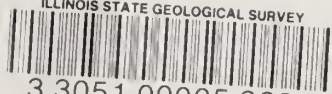





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# ENVIRONMENTAL GEOLOGY NOTES

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*STUDIES OF LAKE MICHIGAN BOTTOM SEDIMENTS—NUMBER ELEVEN*

## GLACIAL TILLS UNDER LAKE MICHIGAN

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## STUDIES OF LAKE MICHIGAN BOTTOM SEDIMENTS—NUMBER ELEVEN

## GLACIAL TILLS UNDER LAKE MICHIGAN

*Jerry A. Lineback, David L. Gross, and Robert P. Meyer*

## ABSTRACT

Four glacial till units have been differentiated under Lake Michigan south of Frankfort, Michigan. Each till was sampled by coring and each has a distinctive mineralogy. Distribution and stratigraphy of the tills were determined by high-resolution seismic reflection profiling.

The three older tills underlie the Two Creeks forest bed, are Woodfordian in age, and are assigned to the Wedron Formation. The lowest of these, the Wadsworth Till Member, is found in the moraines surrounding the southern margin and under the southern end of the lake. It is gray and illitic. The Shorewood Till Member (new) overlies the Wadsworth, is reddish gray, and contains less illite than the Wadsworth. The Shorewood Till forms a prominent terminal moraine on the lake floor south of Milwaukee, Wisconsin, and Muskegon, Michigan. The Manitowoc Till Member (new) is the youngest till of the Wedron Formation, is reddish brown, and contains less illite and more carbonate than the underlying tills. It reaches southward to the north slope of the Mid-lake High north of Milwaukee. All three Wedron tills under the lake are relatively dolomitic, unlike the overlying Two Rivers Till Member of an unnamed formation, which contains relatively more calcite. The Two Rivers Till Member overlies the Two Creeks forest bed and is Valderan in age. It extends as far south as Manitowoc, Wisconsin, and Ludington, Michigan, but is so patchy in distribution that the Manitowoc Till occurs at the lake floor in many places north of Manitowoc.

Glacial lacustrine sediments (Equality Formation) of the same age as the Wedron tills are thin. The South Haven and Sheboygan Members of the Lake Michigan Formation contain red, clayey rock-flour outwash derived from melting of the Valderan glacier. They are found both north and south of the terminus of the Two Rivers Till Member, indicating that deposition of the Lake Michigan Formation did not begin until the glacier front had melted northward beyond Frankfort. The younger members of the Lake Michigan Formation were deposited after glacial influence had left Lake Michigan and are derived from erosion of older tills around the lake and in the drainage basin.

## INTRODUCTION

Lake Michigan occupies a depression eroded largely in Devonian and Mississippian shales and siltstones by Pleistocene glaciers and in part filled by deposition of glacial till (fig. 1). The tongue-shaped form of the lake is no accident; it results from the southward movement of narrow tongues of ice along the axis of the bedrock strike during several glacial episodes. That the present lake-form is the result of many glaciations is without doubt. However, the most recent glacial advances have all but destroyed evidence of earlier advances.

High-resolution seismic profiling and coring of the bottom sediments of Lake Michigan by the Illinois State Geological Survey in conjunction with the University of Wisconsin in recent years have shown that in addition to previously recognized lacustrine units, four major glacial till units can be recognized underlying the lake south of Frankfort, Michigan. All of these tills and lacustrine sediments are believed to be latest Woodfordian (13,500 radiocarbon years B.P.) in age or younger. Nearly 1,860 miles (3,000 km) of seismic profiles and several hundred cores have been taken for this and earlier, related studies. Detailed studies of sediments in the lake north of Frankfort, Michigan, have not yet been done.

The purpose of this paper is to show that the various tills can be separated both by seismic profiling and, compositionally, by X-ray diffraction studies of clay minerals, carbonates, and other till components. Knowledge of the till stratigraphy permits an understanding of the earliest stages of formation of Lake Michigan and of the deposition of younger, lacustrine sediments in it.

The results of previous seismic profiling in Lake Michigan, in the summers of 1970 and 1971, were reported by Lineback et al. (1971) and Lineback, Gross, and Meyer (1972), who also discussed the geophysical technique used (see also Moore and Meyer, 1969). In the 1972 investigation, reported here, essentially the same technique was used. Coring techniques have been described previously by Gross et al. (1970) and Lineback, Ayer, and Gross (1970). Descriptions of cores collected during the October 1972 cruise are included in the appendix. A summary of the interpretations presented in this paper was given by the authors (1973). The composition of sediments under Lake Michigan was discussed by Gross et al. (1972), the depositional patterns of lacustrine sediments by Lineback and Gross (1972), and the velocity of sound in sediments by Silver and Lineback (1972).

## Acknowledgments

We appreciate the valuable assistance of Captain Richard Thibault and the crew of the R. V. *INLAND SEAS* and of the University of Michigan Great Lakes Research Division, which operated the ship under sponsorship of the National Science Foundation.

The seismic equipment was provided under the University of Wisconsin Sea Grant Program and operated by the Geophysical and Polar Research Center, Department of Geology and Geophysics, University of Wisconsin, Madison.



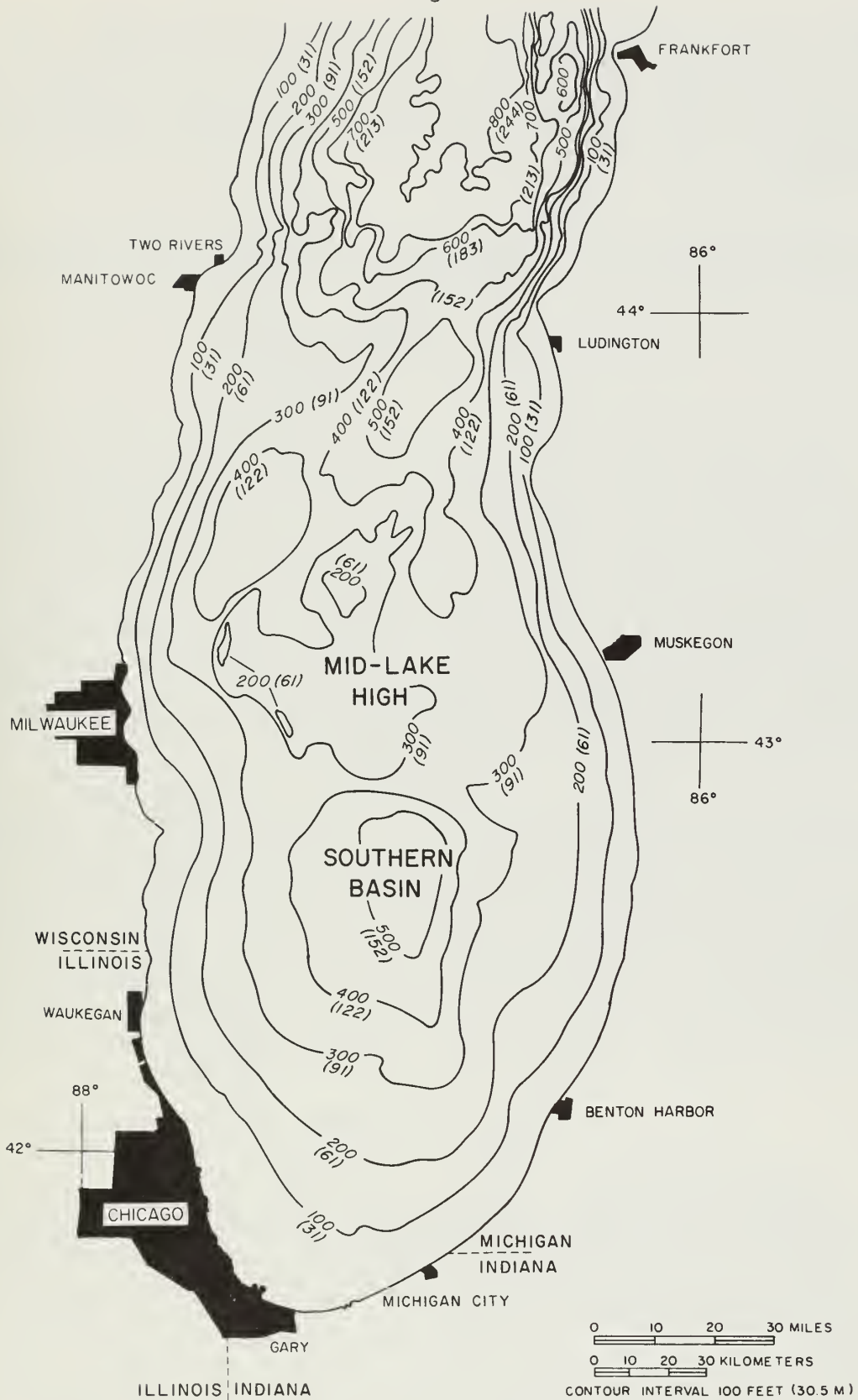


Fig. 1 - Bottom topography of the southern two-thirds of Lake Michigan. Zero datum is mean low water level, 576.8 feet (175.8 m).

R. P. Meyer was in charge, aided by L. A. Powell and William Unger. The remainder of the scientific crew for the October 1972 cruise included Lineback, Gross (Chief Scientist), Jonathan Berkson, Susan Avcin Buckley, Larry Camp, Leon Follmer, Joyce Frost, William Harfts, Leonard Henderson, Norman Hester, George Hughes, Lee Jones, Harry Leland, Peter Lindahl, Philip Reed, and Marshall Silver.

Clay mineralogy by X-ray was done in the laboratories of the Illinois State Geological Survey by H. D. Glass, who also compared the mineralogy of the sub-lake tills with that of samples of till from onshore localities.

#### BOTTOM TOPOGRAPHY AND SEDIMENTS

The bottom topography of the southern two-thirds of Lake Michigan is complex. The central third of the lake, near Frankfort, consists of a deep basin with steep rises near shore (fig. 1). Water depths greater than 900 feet (274 m), the deepest in Lake Michigan, have been recorded in this basin. South of a rise between Two Rivers, Wisconsin, and Ludington, Michigan, the water is shallower, about 400 feet (122 m) deep. Basins greater than 400 feet (122 m) deep and containing lacustrine sediment extend east and west of a wedge of rugged topography connected to the Mid-lake High. The Mid-lake High is an area of till-covered bedrock hills between Milwaukee and Muskegon, Michigan, that separates the southern basin from the central part of the lake. The southern basin is simpler, consisting of a relatively smooth closed depression with water depths of more than 500 feet (152 m) at the center.

Glacial till under Lake Michigan overlies Paleozoic bedrock except where bedrock outcrops. Areas of thin till over bedrock are found along the Mid-lake High and along the topographic rise between Two Rivers and Ludington (fig. 2). Areas of thick till with no significant overlying sediment also are found along the Mid-lake High and along the rise near Two Rivers. Additional areas underlain by thick till occur in the shallow water around the margin of the lake, especially in the southwestern corner near Chicago. Most of the remaining areas of the lake (fig. 2) have at least a thin covering of late glacial and post-glacial lacustrine sediments. The lacustrine sediments are thickest near the centers of topographic low points (basins) on the lake floor.

#### TILL STRATIGRAPHY

Glacial till has been recognized on seismic profiles from Lake Michigan by Lineback et al. (1971) and Lineback, Gross, and Meyer (1972). Superposition of till units was noted in the 1972 report, but it was not until two long north-south seismic profiles were taken in the fall of 1972 that the superposition of multiple till units could be defined (fig. 3). The profiles extend from the southern shore of the lake to the latitude of Frankfort (fig. 4), and at least four major glacial till units have been recognized on the profiles. Cores were taken of each of the four till units where it lies at the lake floor or is covered only by thin lacustrine sediments (fig. 4). Mineralogical analyses of

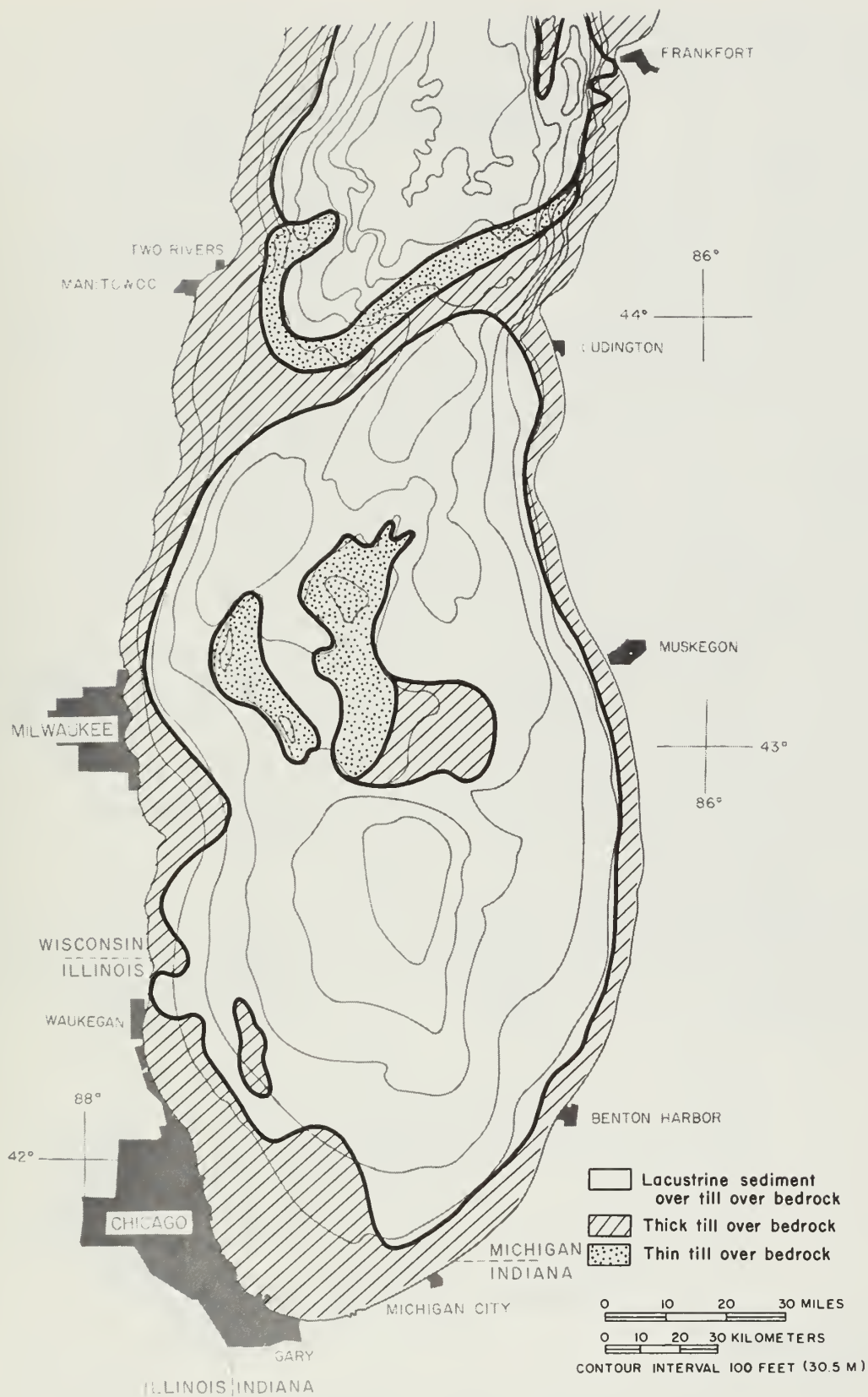


Fig. 2 - Generalized geological map of the floor of Lake Michigan south of Frankfort, Michigan.

PLEISTOCENE			SERIES		
WISCONSINAN			STAGE		HOLOCENE STAGE
WOODFORDIAN SUBSTAGE			VALDERAN SUBSTAGE		LAKE MICHIGAN
			TWOCREEKAN SUBSTAGE		

Fig. 3 - Late Pleistocene sediments underlying southern and central Lake Michigan, south of Frankfort, Michigan.

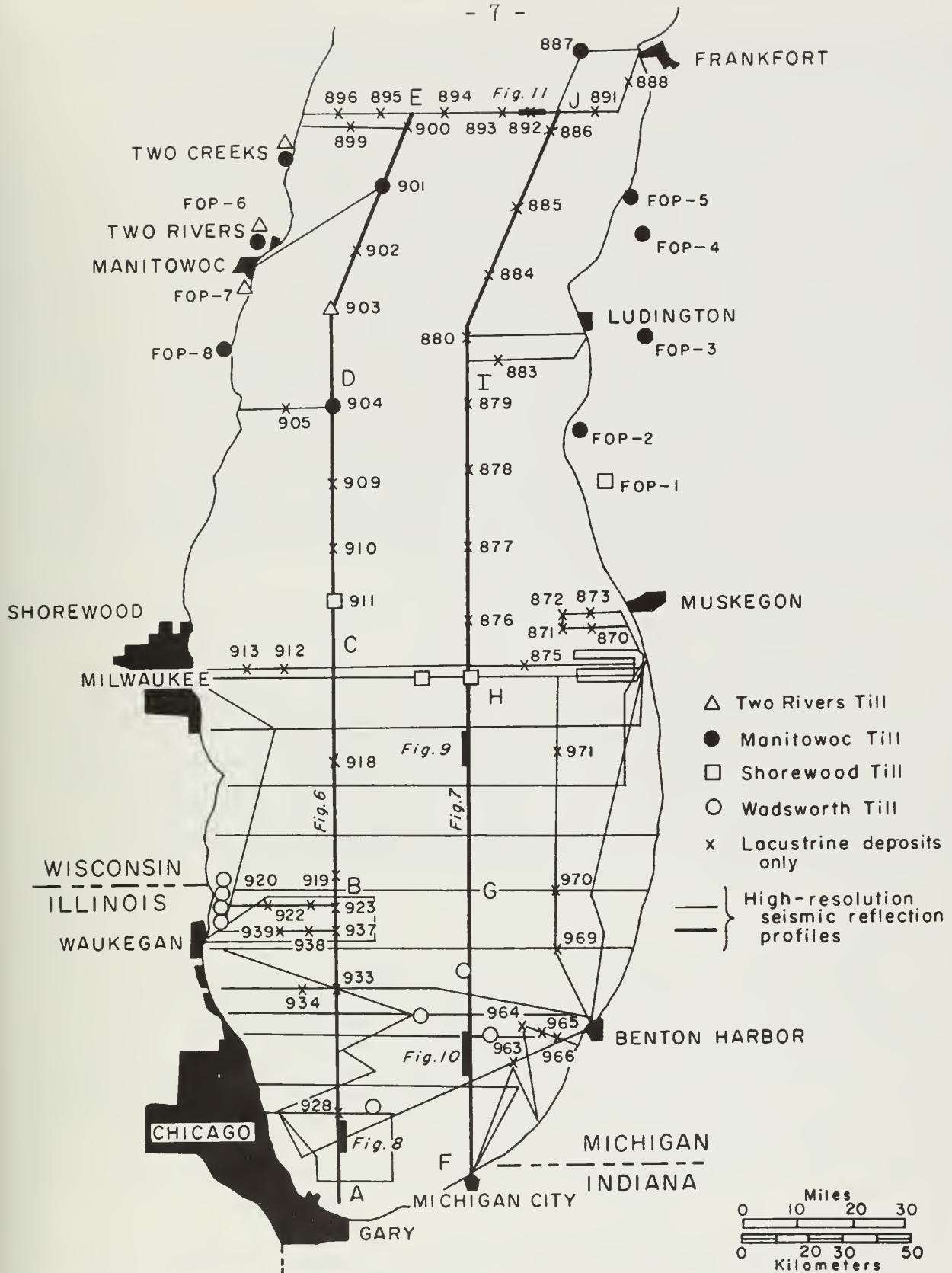


Fig. 4 - Locations of north-south cross sections (figs. 6 and 7); of detailed cross sections (figs. 8, 9, 10, and 11); and of cores and onshore samples containing till and analyzed for this study. Numbers refer to descriptions in appendix.



core samples of the four tills show that each has a distinctive mineralogy. Additional samples from onshore localities have been examined by the same methods (fig. 4, table 1).

The Wadsworth Till Member of the Wedron Formation (fig. 3) is the oldest known till unit; it is found at the southern end of the lake (figs. 5, 6, 7). It is identical to the tills of the Lake Border Morainic System. The Shorewood Till Member is found overlying the Wadsworth Member along the Mid-lake High and extends as far south as Waukegan, Illinois (fig. 5). It is a member of the Wedron Formation, as is the next higher till, the Manitowoc Till Member, which extends southward to the north slope of the Mid-lake High (fig. 5). The Two Rivers Till Member (of an unnamed formation) (fig. 3) is found, in the lake, along the eastern shore and, in places, as patches in the area between Ludington and Manitowoc. In the deep water north of the Ludington-Two Rivers line, the Manitowoc Till is commonly the youngest till present as far north as the seismic profiles were run, because the overlying till is present only in patches or is absent. The Two Rivers Till Member is believed to be Valderan in age and is equivalent to the till overlying the Two Creeks forest bed (Black, 1970). The Two Rivers and Manitowoc Tills are of similar composition, except for calcite content, and are different in composition from the Shorewood Till. The Shorewood Till is intermediate in composition and transitional between the upper two tills and the Wadsworth Till (table 1).

#### Wedron Formation

The Wedron Formation was defined by Frye et al. (1968) to include glacial tills and intercalated deposits lying between the Morton Loess or Robein Silt and the top of the till below the Two Creeks forest bed at Two Creeks, Wisconsin. Several members of this formation have subsequently been defined in Illinois by Willman and Frye (1970). The youngest of these is the Wadsworth Till Member. At least three tills lie above the Wadsworth Till in the Lake Michigan Basin, and two of these are believed to underlie the Two Creeks deposits and hence are also assigned to the Wedron Formation in this report (fig. 3).

#### Wadsworth Till Member

The Wadsworth Till Member was named by Willman and Frye (1970) for Wadsworth, Lake County, Illinois. The Wadsworth consists of gray clayey till and is found in the Lake Border Morainic System, the Tinley Moraine, and part of the Valparaiso Morainic System. The Wadsworth is characterized by an illite content always greater than 70 percent and by a less than 10 percent expandable clay minerals content when unweathered. It contains more dolomite than calcite and has a gray color and clayey grain size (table 1). The Wadsworth under Lake Michigan is identical with unweathered samples of the onshore till from the Lake Border Moraines and is different mineralogically from the overlying tills (table 1).

In the southern and southeastern parts of the lake, the Wadsworth is present at the lake floor or under younger non-till sediments (fig. 5). In the shallow water east and northeast of Chicago, the Wadsworth is the surficial sediment or is overlain by thin gravel or sand (fig. 6). Under the lake the thickness of the Wadsworth ranges from a few inches to at least 60 feet (18 m)

TABLE 1 - COMPOSITION OF TILLS UNDER LAKE MICHIGAN, ONSHORE NEAR LAKE MICHIGAN,  
AND AT THE TWOCREEKAN TYPE LOCALITY AT TWO CREEKS, WISCONSIN

	Member	Calcite (counts/sec)	Dolomite (counts/sec)	Expandables (%)	Illite (%)	Chlorite (%)	Vermiculite (relative amount)	Color of 2 $\mu$ fraction	Number of samples
Samples from under the lake	Two Rivers Till	84	55	19	58	24	high	light reddish brown 5 YR 6/4	2
	Manitowoc Till	73	146	18	55	24	high	pink 5 YR 7/4 - 6/3	7
	Shorewood Till	37	58	15	60	25	moderate	pinkish gray 5 YR 6/2	3
	Wadsworth Till	38	50	8	72	20	low	gray 10 YR 5/1	9
Samples from onshore	Two Rivers Till <sup>a</sup>	59	46	24	54	23	high	reddish brown	3
	Manitowoc Till <sup>a</sup>	57	79	24	55	21	high	reddish brown	12
	Shorewood Till <sup>a</sup>	62	74	21	65	14	moderate	pinkish brown	1
	Wadsworth Till <sup>b</sup>	48	56	8	72	20	low	gray	6
Samples from Two Creeks type section	Two Rivers Till <sup>c</sup>	55	40	20	53	27	high	reddish brown	1
	Two Creeks silt <sup>c</sup>	50	65	9	66	25			1
	Manitowoc Till <sup>c</sup>	52	63	20	56	24	high	reddish brown	1

<sup>a</sup> Samples collected by Lineback on 1973 Midwestern Friends of Pleistocene Field Trip.

<sup>b</sup> Samples collected by A. M. Jacobs, 1973, from Lake Border Moraines.

<sup>c</sup> Samples collected by John Kempton, 1970.

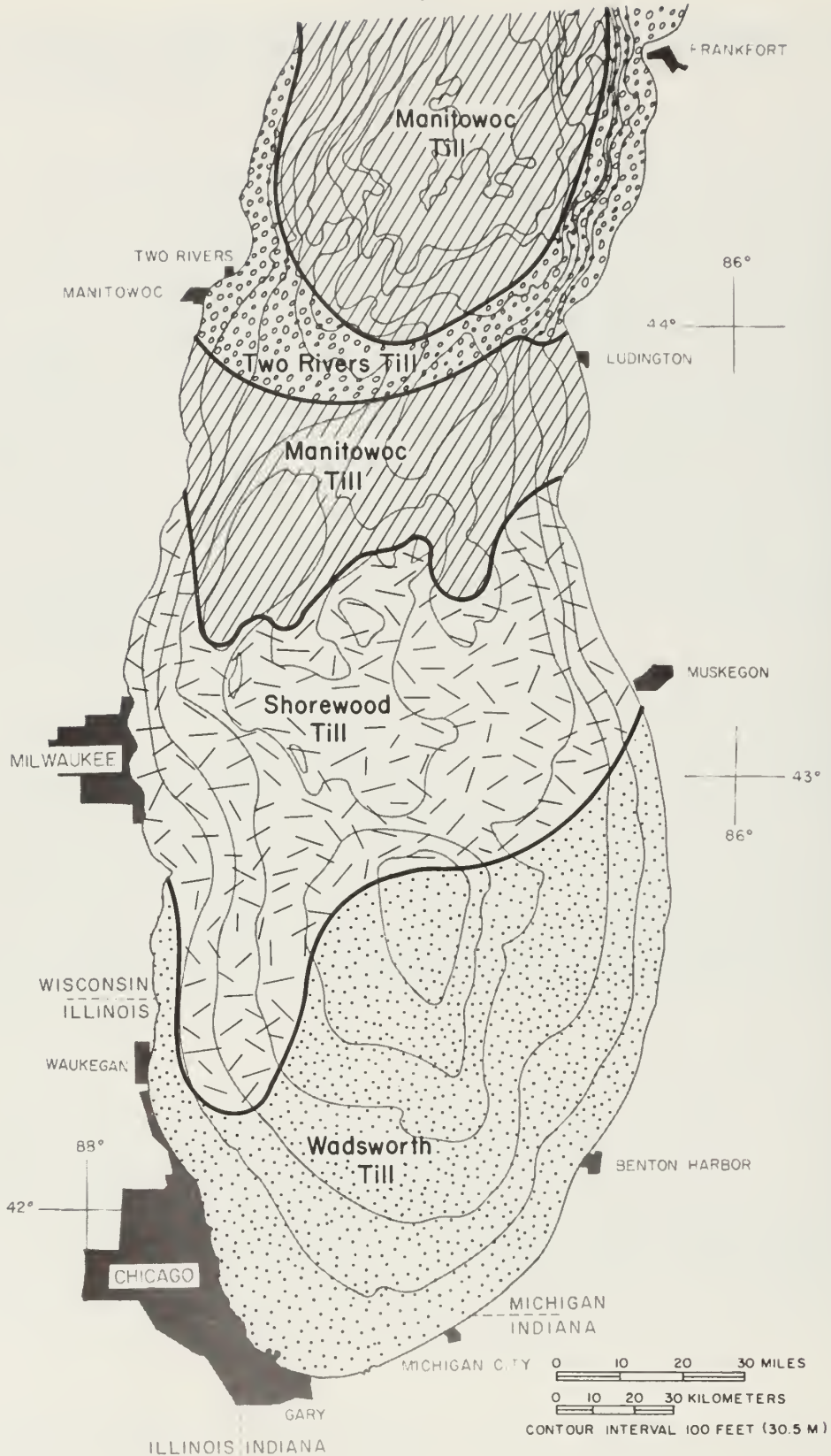


Fig. 5 - Distribution of glacial till units under Lake Michigan.

in the southwest corner (fig. 8). A few irregular stratigraphic breaks can be seen within the till on the seismic profiles (fig. 6), perhaps marking the boundary between the Wadsworth and older tills. Tills older than the Wadsworth undoubtedly were deposited in southern Lake Michigan, but most if not all of these tills were eroded by the glaciers of the Woodfordian Substage. We have not sampled any tills in Lake Michigan older than the Wadsworth (about 13,500 radiocarbon years B.P.), and we have not found any positive evidence on the seismic profiles that any till is older than the Wadsworth. In many places the base of the till (top of bedrock) cannot be seen because the acoustic signal was entirely scattered within the till.

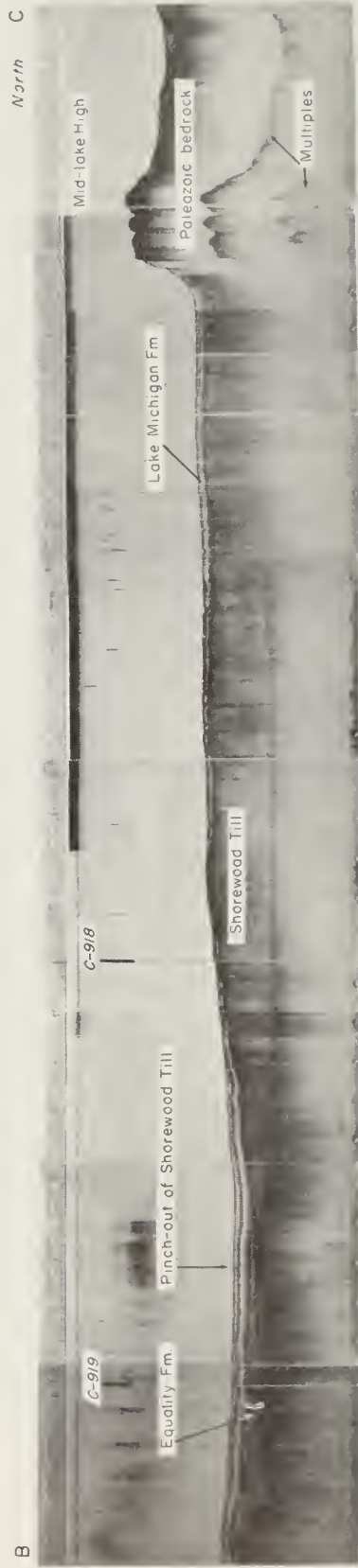
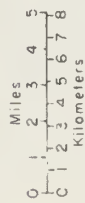
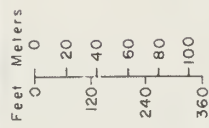
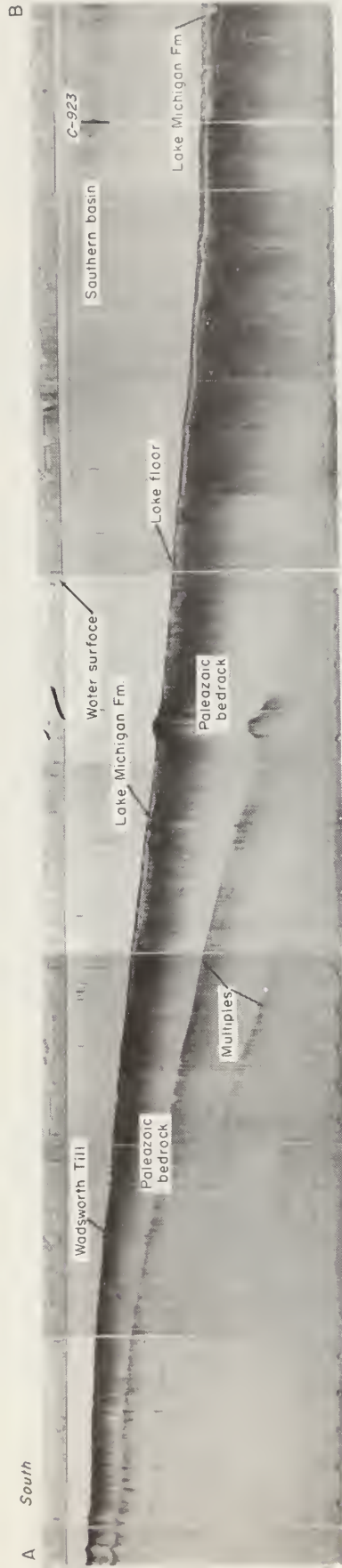
The Wadsworth forms a relatively smooth lake floor at the southern end of the lake, and no submerged moraines related to the Wadsworth have been identified. The Wadsworth is overlain by sand and gravel believed to be glacial outwash and lag deposits left by lake-floor currents. In areas where younger lacustrine sediments are absent, the sand often shows large-scale ripple marks and linear ridges (Berkson, Lineback, and Gross, in preparation).

#### Shorewood Till Member

The Shorewood Till Member of the Wedron Formation is here named for the town of Shorewood, Milwaukee County, Wisconsin (fig. 3). The type section is brown clayey till present from 82 cm to 221 cm in core 911 (appendix, section 2) located about 30 miles (48 km) east of the town (fig. 4). The core was taken at latitude  $43^{\circ}13.9'N.$ , longitude  $87^{\circ}22.1'W.$  in 295 feet (89.9 m) of water on the Mid-lake High. The Shorewood Till is of late Woodfordian age. It is a clayey till intermediate in composition and color between the Wadsworth and Manitowoc Tills (table 1). The Shorewood contains more expandable clay minerals and less illite than the Wadsworth, and is pinkish to brownish to reddish gray rather than gray like the Wadsworth or brown to reddish brown like the Manitowoc. The Shorewood Till contains more dolomite than calcite but, like the Wadsworth, is lower in total carbonate than the Manitowoc and Two Rivers Tills. It contains vermiculite (iron-rich chlorite) among the chlorite-type minerals in the clay fraction, characteristic of the chlorites in reddish tills of Woodfordian age in the Lake Michigan Lobe and different from the non-vermiculite chlorites found in the Wadsworth and other gray tills. The Shorewood, however, contains less vermiculite than the Manitowoc and Two Rivers Tills, indicating that it is transitional in composition between the Wadsworth and the younger, more reddish tills.

The Shorewood Till Member forms a prominent terminal moraine on the lake floor (figs. 6, 7, 9), and the till reaches 160 feet (49 m) in thickness at places along the moraine. The subsurface boundary between the Wadsworth and the Shorewood can be traced for several miles north of the moraine front on profile A-D (fig. 6). The till thins northward, but is irregular in thickness because of bedrock topography, particularly along the Mid-lake High. The till is thick over bedrock depressions and thin over highs, smoothing over the relatively rugged bedrock topography that characterizes the Mid-lake High. It extends farther south along the west side of the lake than on the east side (fig. 5) and is found on the lake bottom only a few miles east of Waukegan, Illinois. The Shorewood is probably related to the reddish gray tills found along the lake shore at Milwaukee and Muskegon.







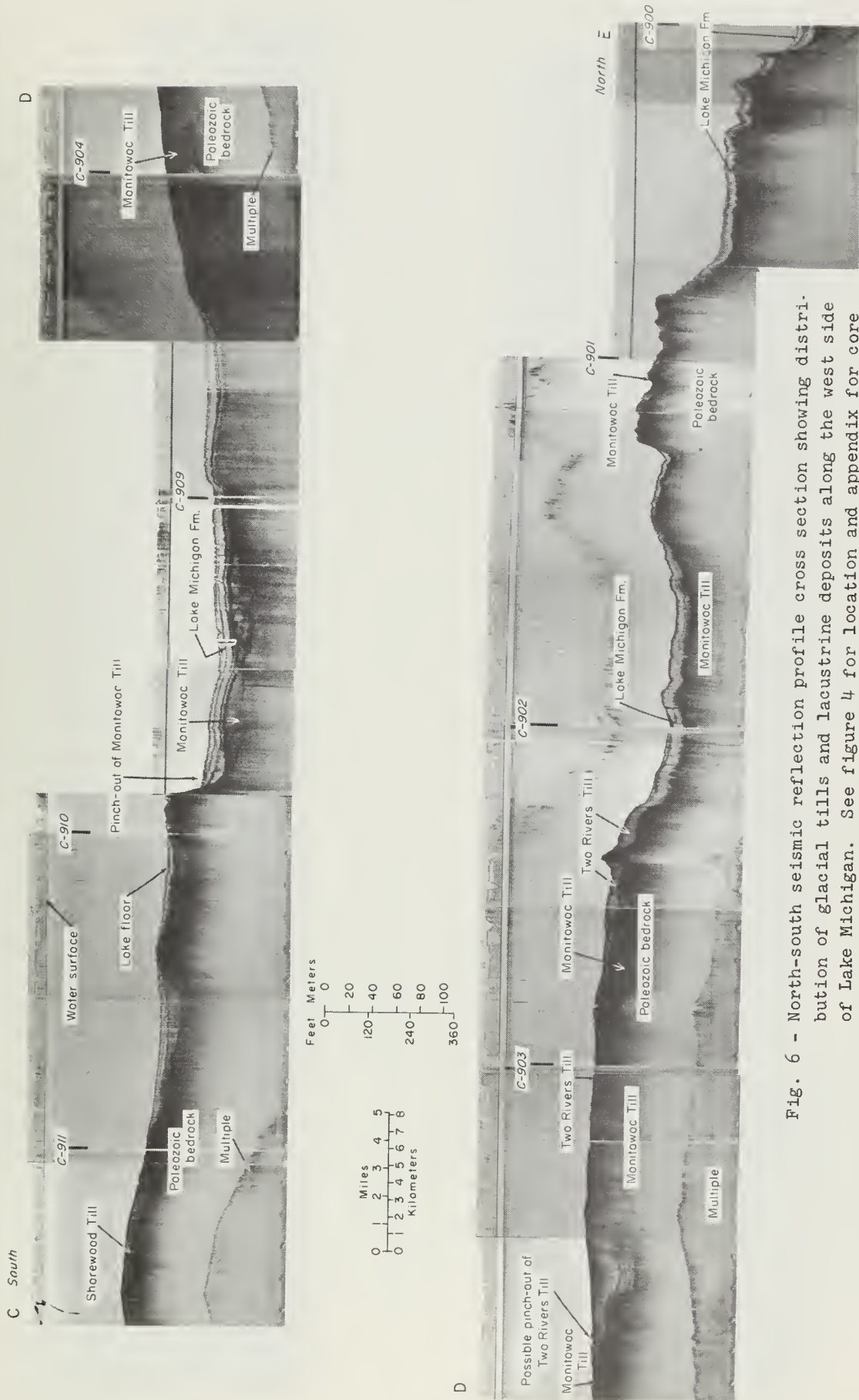
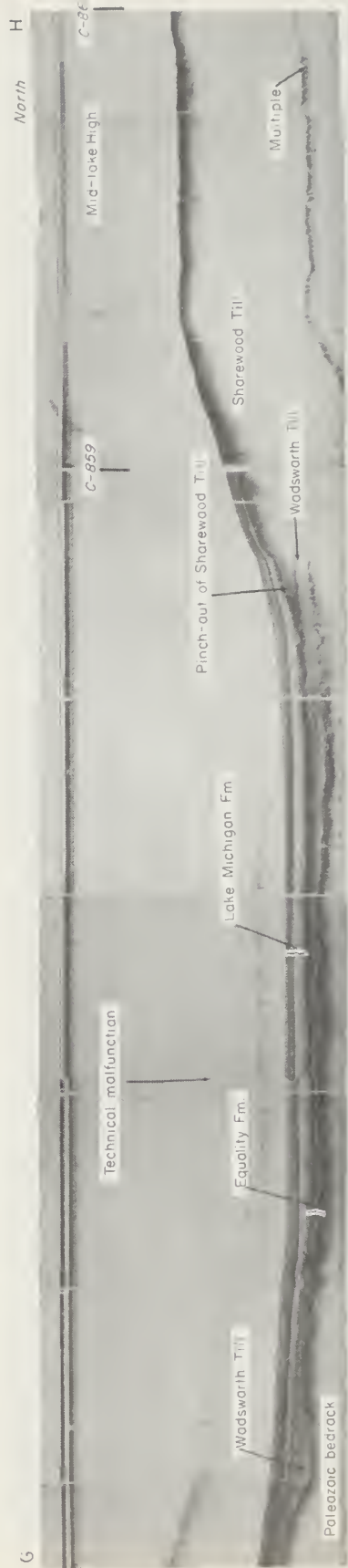
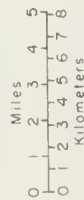
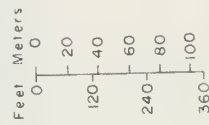
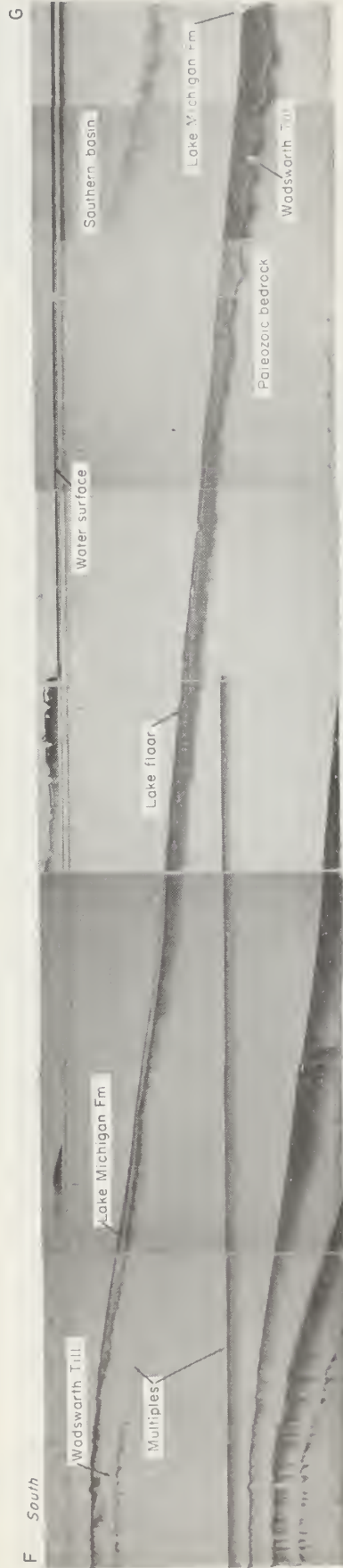


Fig. 6 - North-south seismic reflection profile cross section showing distribution of glacial tills and lacustrine deposits along the west side of Lake Michigan. See figure 4 for location and appendix for core descriptions.



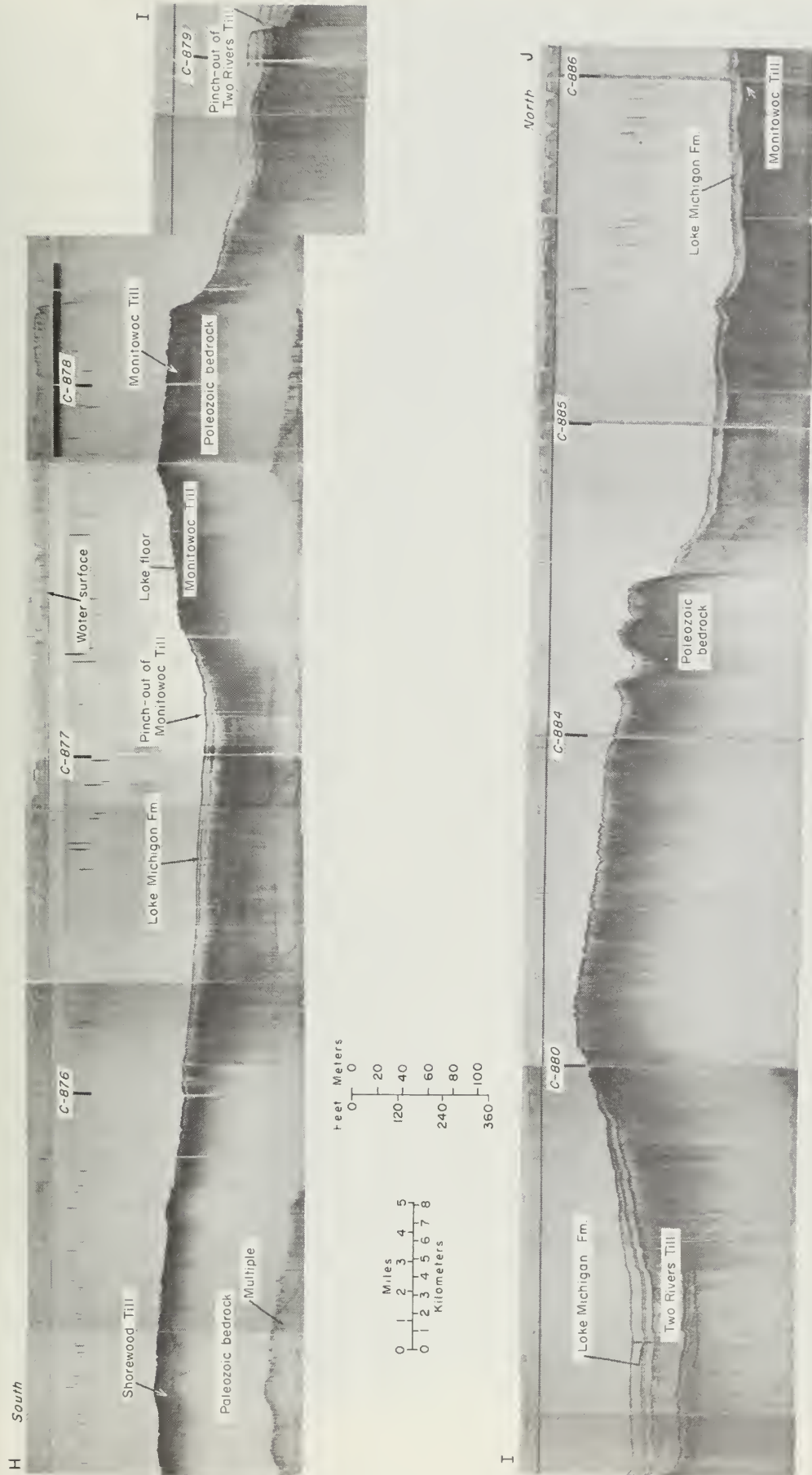


Fig. 7 - North-south seismic reflection profile cross section showing distribution of glacial tills and lacustrine deposits along the east side of Lake Michigan. See figure 4 for location and appendix for core descriptions.



### Manitowoc Till Member

The Manitowoc Till Member may be the youngest member of the Wedron in the Lake Michigan Basin and is here named for Manitowoc, Manitowoc County, Wisconsin. The type section is brown clayey till found from 259 cm to 328 cm in core 904 (lat. 43°45.0'N., long. 87°22.2'W.) located 28 miles (45 km) south-east of Manitowoc (appendix, section 2). The Manitowoc is believed to be equivalent to the till that underlies the Two Creeks forest bed and therefore to be latest Woodfordian in age. The Manitowoc is a brown to reddish brown clayey till and occurs at the lake floor or below younger, lacustrine sediments at most places north of the Mid-lake High (fig. 5). The southern limit of the Manitowoc is marked by a prominent pinch-out (figs. 6, 7). The glacier that deposited the Manitowoc moved southward along depressions on the lake floor and split into two small lobes on the east and west sides of a northward extension of the Mid-lake High (fig. 5). It failed to rise very far up the northern slope of the Mid-lake High. The till also overlies considerable bedrock topography, and its thickness ranges from inches to more than 100 feet (31 m).

The Manitowoc contains more expandable clay minerals, less illite, and more vermiculite than does the Shorewood (table 1). The Manitowoc also contains more total carbonate, with dolomite greatly predominating.

### Unnamed Formation of Valderan Age

#### Two Rivers Till Member

South of Frankfort the Two Rivers Till Member is the youngest till under the lake (fig. 3). This till was formally named the Two Rivers till by Evenson (1973) and, as that is the only rock-stratigraphic name applied to this till, the name is accepted here. Evenson (1973) did not provide a detailed measured description of the type section, which is located in a gravel pit near Wisconsin 42, NE $\frac{1}{4}$ NE $\frac{1}{4}$  sec. 36, T. 20 N., R. 24 E., just north of Two Rivers, Manitowoc County, Wisconsin, but a description of the locality may be found in Evenson, Eschman, and Farrand (1973, p. 58). Nor did he directly indicate the stratigraphic rank of the Two Rivers till. The name Two Rivers Till Member is here used in member rank and assigned to an as yet unnamed formation of Valderan (post-Twocreekan) age. In making this assignment we recognize the possibility that other tills of Valderan age may exist in the Lake Michigan Basin north of Frankfort.

The Two Rivers Till Member is present on the lake floor in thin patches (0 to 30 feet, 0 to 9 m) between Manitowoc and Ludington (figs. 5, 6, 7). A lateral moraine-like body of Two Rivers Till is present along the eastern shore of Lake Michigan between Ludington and Frankfort (fig. 5), perhaps indicating that the Two Rivers glacier did not leave the lake basin along the east side south of Frankfort. The Two Rivers Till is reddish brown and is generally more reddish than the Manitowoc. At the Two Rivers type section, and at other outcrops of tills of the Valderan Substage, the Two Rivers Till contains incorporated blocks of till believed to be equivalent to Manitowoc as defined here (Evenson, 1973; Evenson, Eschman, and Farrand, 1973; Black, 1970). The Two Rivers Till contains about the same amount of expandable clay minerals, illite,

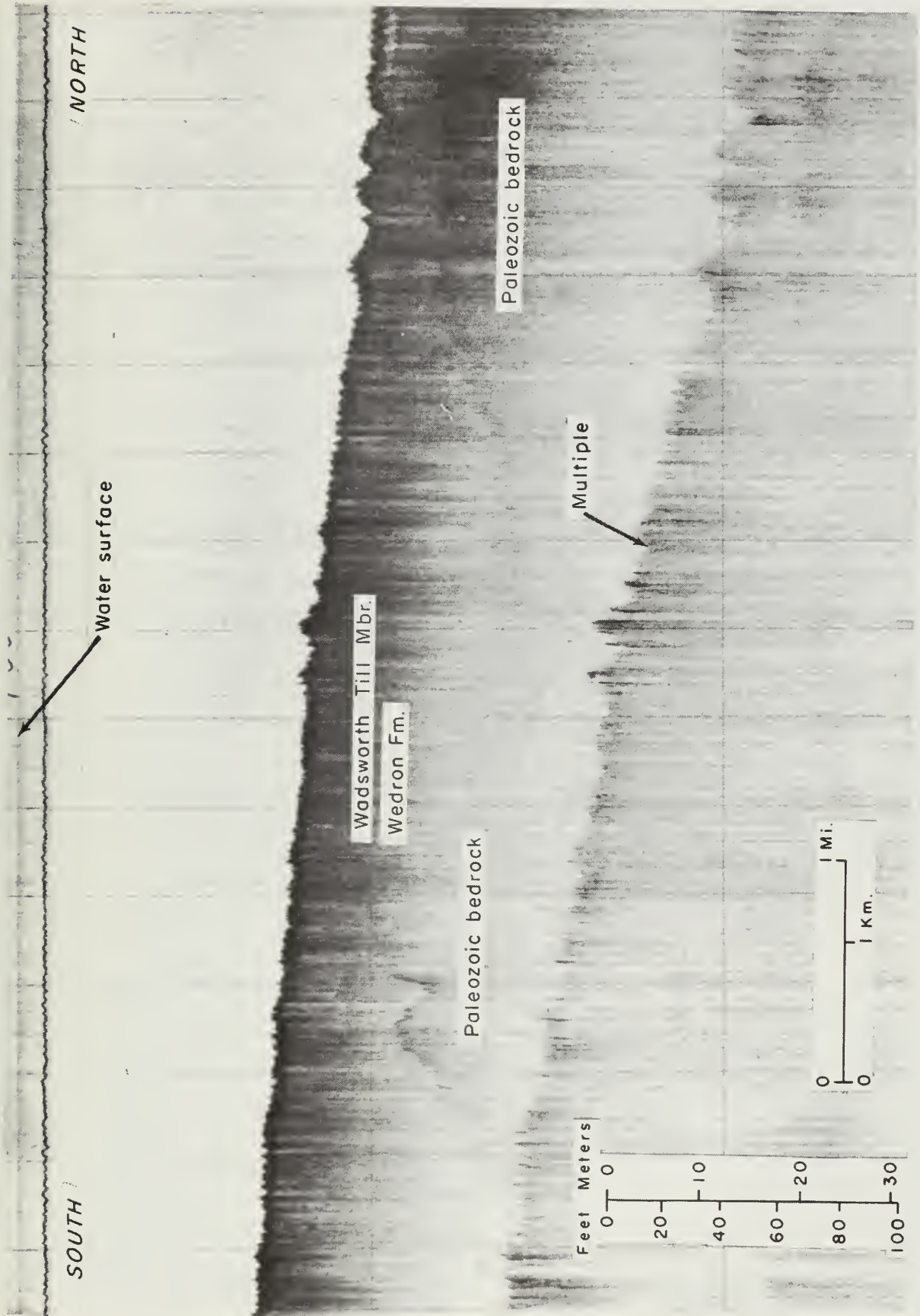


Fig. 8 - Enlarged seismic reflection profile from an area northeast of Chicago showing the Wadsworth Till Member of the Wedron Formation overlying Paleozoic bedrock. See figure 4 for location.



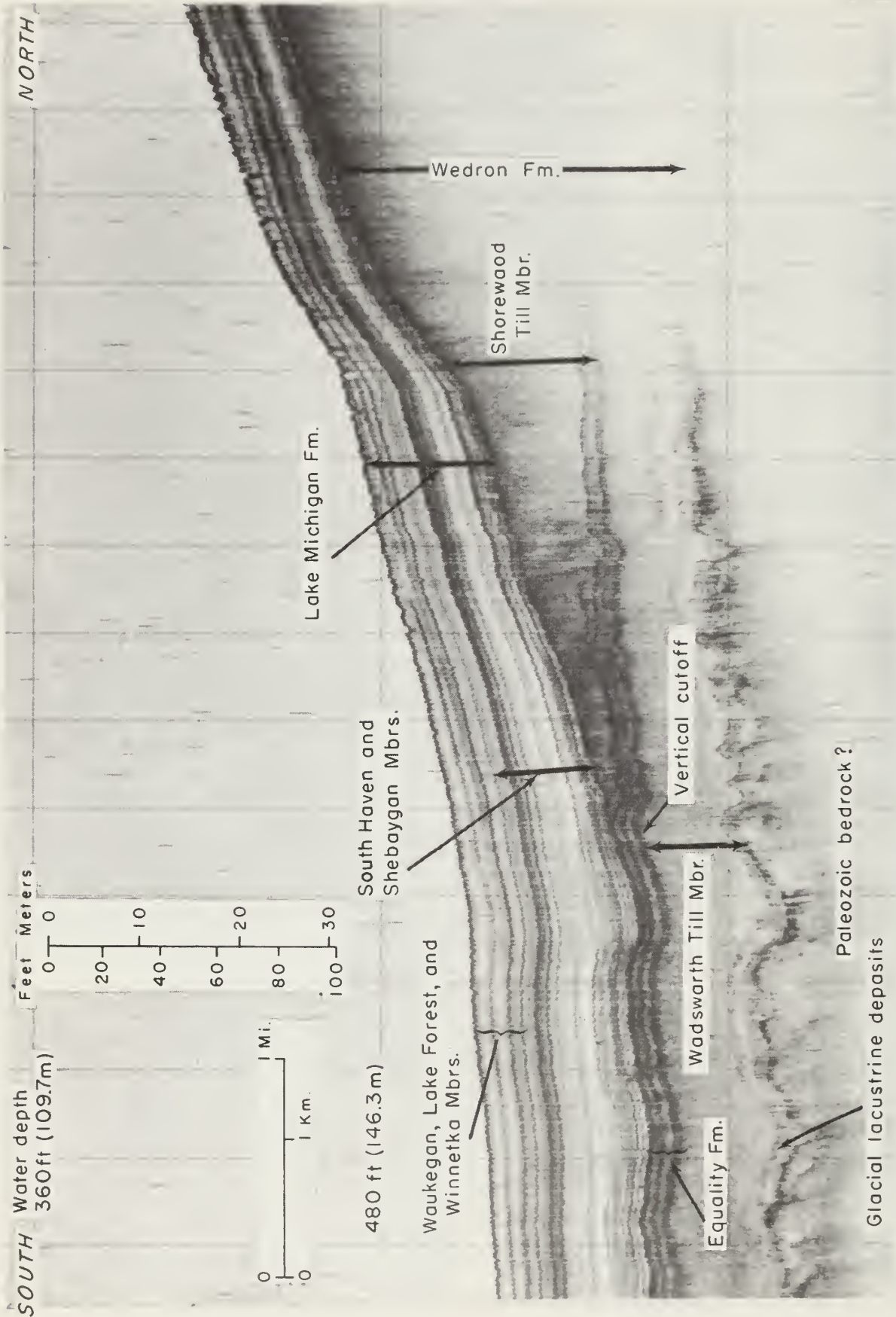


Fig. 9 - Enlarged seismic reflection profile from an area near the northern end of the southern lake basin showing the southward pinch-out of the Shorewood Member of the Wedron Formation. Note that the Equality Formation is separated from the Shorewood Till Member of the Wedron Formation by a vertical cutoff at the pinch-out of the till in the Shorewood. See figure 4 for location.

and vermiculite as the Manitowoc, but it generally shows more calcite X-ray counts per second than dolomite, indicating relatively less dolomite and less total carbonate in the Two Rivers Till than in the Manitowoc (table 1).

Evenson (1973), Evenson, Eschman, and Farrand (1973), and Evenson, Farrand, and Eschman (1974) questioned the suitability of using Valderan as a time-stratigraphic term for the substage following the Twocreekan. They contend that the till at Valders, Wisconsin, is older than the Two Rivers Till at Two Rivers and Two Creeks, Wisconsin, and that the name Valderan is therefore inappropriate. Even if the two tills do not correlate, the concept of Valderan (Frye et al., 1968; Black, 1974), based on the Valders Drift of Thwaites (1943) and Thwaites and Bertrand (1957), as a time-stratigraphic unit immediately postdating the Twocreekan is not affected, although the suitability of the name may be questioned. The till above the type Two Creeks deposit, which is also the type section for the Valderan Substage, closely resembles the Two Rivers Till by having relatively more calcite and less dolomite than the till below the Two Creeks deposit correlated with the Manitowoc (table 1). Similar stratigraphic superposition of relatively high-calcite-low-dolomite till over otherwise quite similar high-dolomite till occurs at Two Creeks, at the type Two Rivers section, and under the lake east of Manitowoc. We believe that this superposition of compositionally different tills strongly indicates the correlation of the Two Rivers Till with the post-Twocreekan till at Two Creeks and with the till on the lake floor above the Manitowoc. Because our sampling is limited, we recognize that much more work is needed on land and under the lake north of Frankfort to prove this correlation.

#### DISTRIBUTION OF SOFT SEDIMENTS

Clay-pebble conglomerate, sand, silt, and clay, all assigned to the Carmi Member of the Equality Formation (Willman and Frye, 1970), form a thin layer over till in many areas of central and southern Lake Michigan (fig. 3). Thicker deposits of Carmi are present in the deep basins and in front of presumed lake-floor terminal moraines (figs. 6, 7, 9). Thin Equality cannot be separated from the till on many seismic profiles.

The Lake Michigan Formation was defined in the southern part of the lake (Willman and Frye, 1970) and is also found in the deep-water basins north of the Mid-lake High (figs. 3, 6, 7). It ranges from 0 to 60 feet (18 m) in thickness. Details of the distribution and thickness of the formation, and its members, derived from seismic profiles and coring in the southern basin, were discussed by the authors (1972) and by Lineback and Gross (1972). The formation consists of six members (fig. 3). The lowermost member is the South Haven Member, which consists of reddish gray to reddish brown clay. Some samples of the South Haven, particularly the northernmost, show evidence of varving or varve-like layering. This unit and the overlying Sheboygan Member average near 80 percent clay-size particles that consist of quartz, feldspar, and other rock minerals in addition to clay minerals (Gross et al., 1972). The Sheboygan is reddish brown clay with a thin persistent (10 to 30 cm) bed of dark gray clay, the Wilmette Bed, near its middle. The South Haven and the Sheboygan mineralogically resemble the Two Rivers Till and are believed to represent rock-flour outwash derived from the melting of the Valderan glacier. The South Haven and Sheboygan



are overlain, in places unconformably (fig. 10), by darker colored, coarser grained clays and silts. The Winnetka Member contains approximately 20 percent more silt than the underlying units (Gross et al., 1972). It is grayish brown to brown silty clay with some thin beds of black clay. The Lake Forest Member contains gray clay with many thin black beds and black mottling. The black coloring is derived mostly from hydrous iron sulfides, and the black beds contain only a little more organic matter than the gray clay. The Waukegan is the youngest member under the lake and consists of dark gray, soft silty clay and clayey silt. The member is widespread, but usually less than 3 feet (1 m) thick. Along the east side of the lake, the Waukegan is more than 32 feet (10 m) thick in a delta-like body (Lineback and Gross, 1972). In places, sand and, rarely, gravel are included in the Waukegan. The Ravinia Member includes the sand of the modern beaches.

The Winnetka, Lake Forest, and Waukegan Members represent sedimentation in the lake since the end of glaciation. The beginning of their deposition probably marks the Wisconsin-Holocene boundary (about 7,000 radiocarbon years B.P.), and deposition is continuing today. The sediment mineralogically resembles the older Wedron Formation tills now surrounding the lake and was derived from them by shoreline erosion or by streams entering the lake.

The stratigraphy of the Lake Michigan Formation north of the Mid-lake High is essentially the same as it is in the southern basin. All members can be recognized and the South Haven Member overlies each of the four major till units under the lake south of Frankfort (fig. 11). If the Two Rivers Till under the lake is correctly correlated here, the base of the Lake Michigan Formation is Valderan in age (fig. 3). Mineralogical evidence indicates that the red clay of the South Haven and Sheboygan Members consists of rock-flour outwash from melting Valderan age glaciers (Gross et al., 1972). Since similar thicknesses of South Haven and Sheboygan occur both north and south of the terminus of the Two Rivers (Valderan) glacier, and also on the Shorewood and Wadsworth Tills, deposition of the Lake Michigan Formation began after the glacier front had reached its maximum advance and had retreated northward beyond Frankfort. Apparently the Woodfordian glaciers did not deposit extensive rock-flour outwash older than the South Haven. That which was deposited is thickest near some lake-floor moraines and is included in the Equality Formation (fig. 9).

During the course of his investigations of Lake Michigan, Hough (1958) collected a piston core 32 feet (10 m) long from the point of deepest water in Lake Michigan, between Frankfort and Manitowoc (fig. 4). This point is crossed by the seismic profile shown in figure 11. Our core 892 penetrated part of the Lake Michigan Formation and Hough's core M-1 penetrated the formation to the till below. Our interpretation of these cores is given in figure 11. The discrepancy in thickness results from compression of sediment in the ISGS gravity corer as opposed to the more nearly true thickness of sediment recovered by the piston corer Hough used. Thicknesses of units from the piston corer closely match the scale of sediment thickness developed by Silver and Lineback (1972) for the seismic profiles used in this study.

The only notable difference between Lake Michigan Formation sediments from the northern basin and the southern basin is that some varving is present in northern samples of the Sheboygan and South Haven red clays but is not obvious in samples from south of the Mid-lake High, perhaps indicating climatic differences during deglaciation.

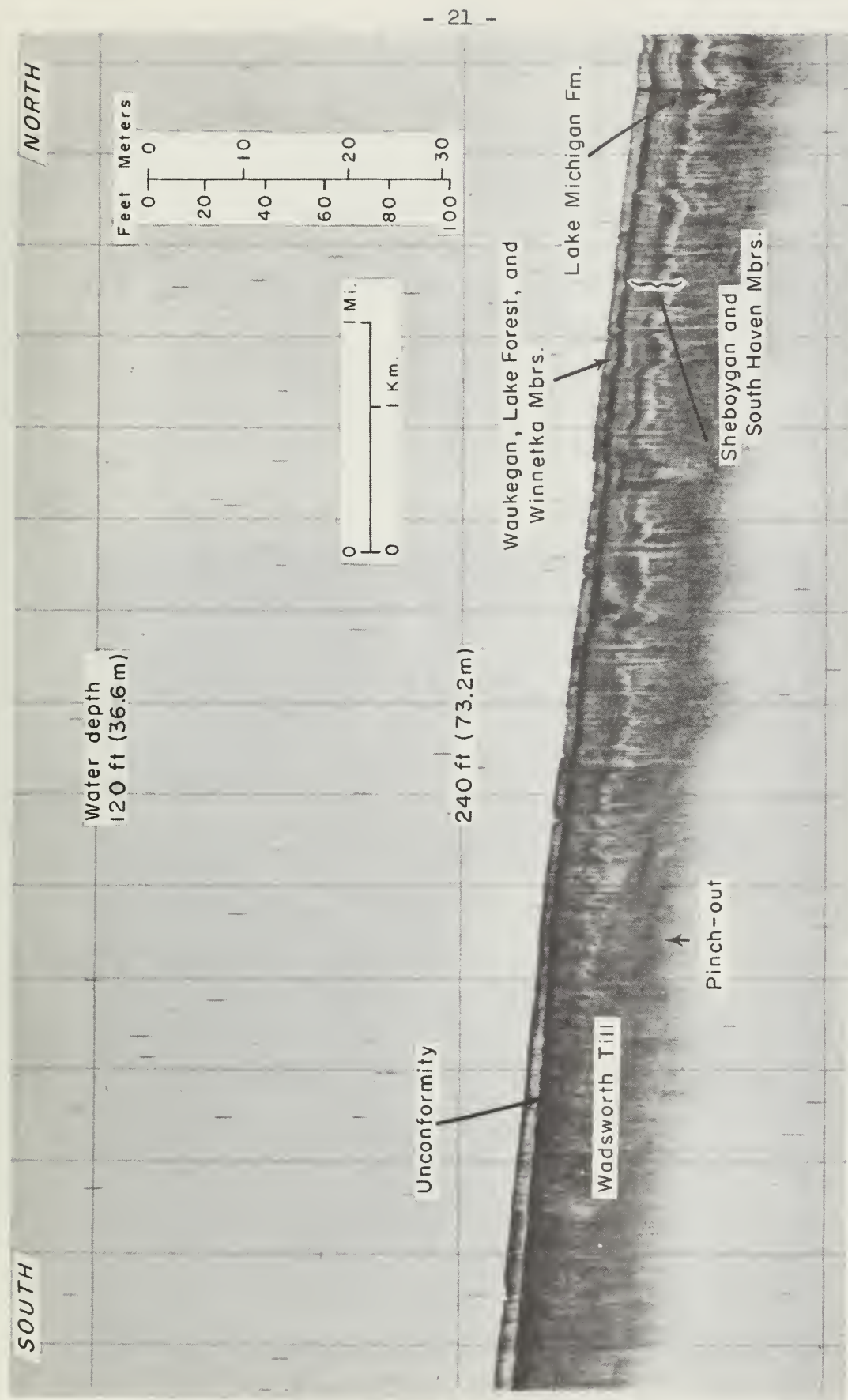


Fig. 10 - Enlarged seismic reflection profile from an area west of Benton Harbor, Michigan, showing the southward pinch-out of the South Haven and Sheboygan Members of the Lake Michigan Formation. See figure 4 for location.

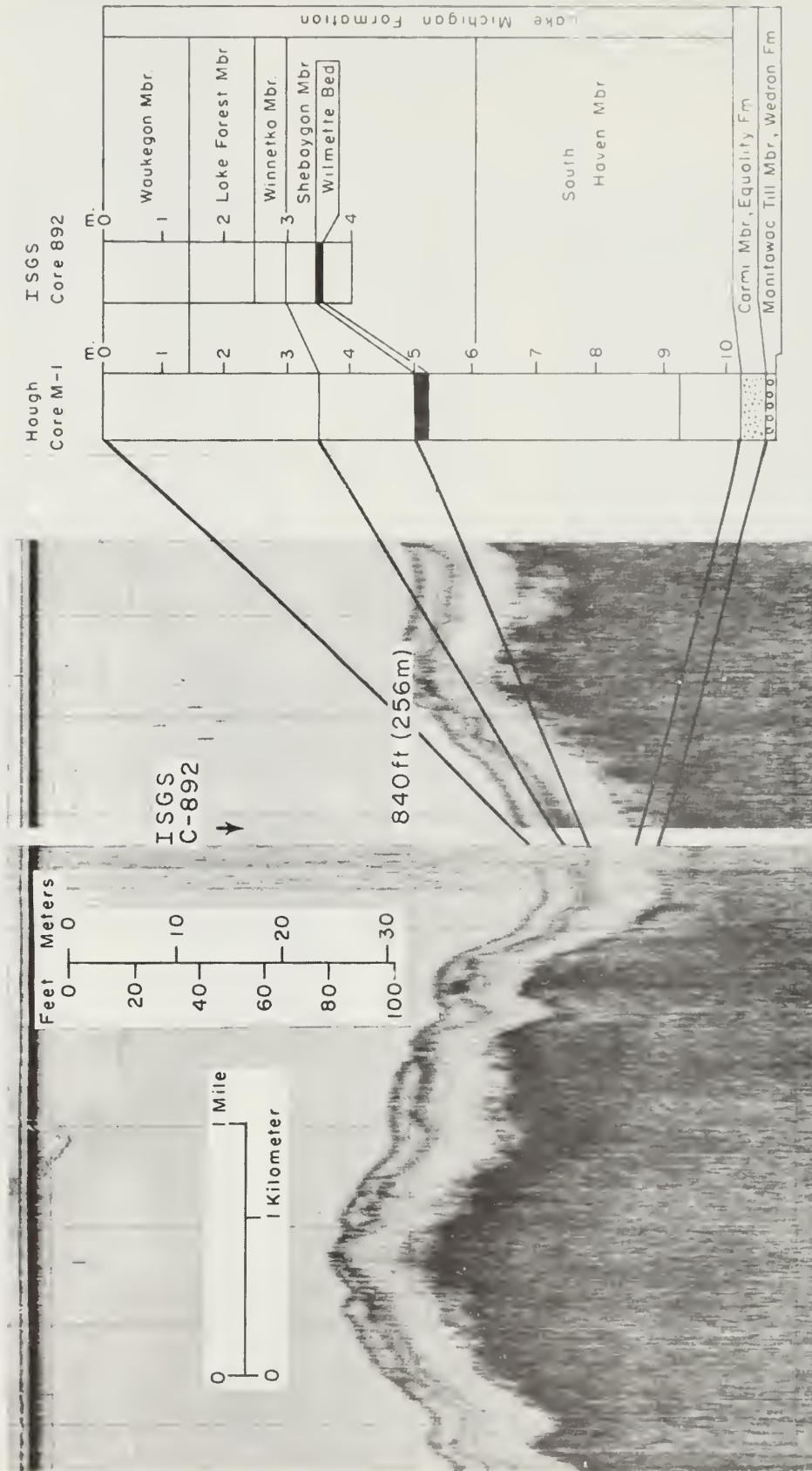


Fig. 11 - Seismic profile from the deepest water of Lake Michigan, between Frankfort, Michigan, and Kewaunee, Wisconsin, and stratigraphy derived from core 892 and a core collected by Hough (1958). See appendix for description of core 892.



# TILL RELATIONSHIPS

The distribution of late Pleistocene tills under Lake Michigan can be shown by figure 5 and the seismic profiles (figs. 6, 7). The Wadsworth Till is related mineralogically to other gray tills of the Wedron Formation such as the Yorkville, Malden, Snider, and Batestown Members (table 2). These gray tills

TABLE 2 -- AVERAGE COMPOSITION OF SEVERAL LATE PLEISTOCENE TILLS

	Calcite (counts/sec)	Dolomite (counts/sec)	Expandables (%)	Illite (%)	Chlorite + Kaolinite (%)
GRAY TILLS					
Wadsworth <sup>a</sup>	48	56	8	72	20
Yorkville <sup>b</sup>	21	34	6	78	16
Malden <sup>b</sup>	18	38	8	77	15
Snider <sup>c</sup>	nd	nd	3	83	14
Batestown <sup>d</sup>	20	29	7	76	17
REDDISH BROWN TILLS					
Two Rivers <sup>d</sup>	72	51	22	55	24
Manitowoc <sup>d</sup>	65	113	21	56	23
Shorewood <sup>d</sup>	50	66	18	63	20
Tiskilwa <sup>b</sup>	26	43	19	65	16
Glenburn <sup>c</sup>	23	31	13	69	18
Capron (Winnebago Fm) <sup>b</sup>	nd	nd	37	50	13

nd - no data.

<sup>a</sup> Collected by A. M. Jacobs, 1973.

<sup>b</sup> Taken from Willman and Frye, 1970.

<sup>c</sup> Taken from Johnson et al., 1972.

<sup>d</sup> Samples reported in this study.

are generally illite-rich and contain less total carbonate than the reddish brown tills. They also contain less vermiculite than the red tills. Color and composition of these tills are not identical everywhere in Illinois, but the average compositions serve to distinguish them throughout the extent of the Lake Michigan Lobe in Illinois.

The Two Rivers, Manitowoc, and Shorewood Till Members are compositionally similar to the older Tiskilwa, Glenburn, and Capron Till Members (table 2). These tills have less illite, more expandable clay minerals, more total carbonate, and more vermiculite than the gray tills. The compositional differences between the Wadsworth and similar gray tills, on the one hand, and the overlying red tills and their older relatives, on the other, is so great as to indicate a major shift in glacial source area. The major constituents of the matrix of the Wadsworth Till appear to have been derived from erosion of Paleozoic bedrock, perhaps within the Lake Michigan Basin itself. The matrix of the reddish vermiculite tills appears to have been derived from erosion of other source areas, perhaps north and west of the lake basin.

Tills under Lake Michigan each represent minor readvances of a generally retreating glacial lobe. Each advance was weaker and reached a lesser distance south than the preceding. The glaciers themselves were largely confined to the lake basin at their southern extremities. The glaciers moved out of the basin during advances, resulting in the burial of silts and organic deposits such as the Two Creeks forest bed in the marginal areas of the lake.

The moraine composed of reddish till that extends south along the Wisconsin lakeshore to Milwaukee, and also southward in Michigan to Muskegon, and previously related to the Valderan (Black, 1970), is correlated with the Shorewood Till under the lake and is late Woodfordian in age. The Manitowoc Till is also found onshore in places and has previously been called Valders or Port Huron. The Manitowoc is also Woodfordian in age since it underlies the Two Creeks forest bed. Deposits of Twocreekan age have not been found during coring of the lake floor. Twocreekan deposits usually consist only of a forest layer, and a forest would not have grown under the lake that must have existed in front of the glacier. The Two Rivers Till, which overlies the Two Creeks forest bed, is Valderan (post-Twocreekan) in age.

Ancestral Lake Michigan formed immediately after glacial ice melted away from the Lake Border Moraines, and the lake has continued until today. Initial lacustrine deposits in the lake were gray clay and silt derived from the glacier that deposited the Wadsworth Till. Each succeeding readvance left a deposit of glacial lacustrine silt, clay, and clay-pebble conglomerate matching the composition of the till deposited. All these glacial lacustrine sediments are placed in the Equality Formation because they have similar lithologies. These deposits are generally thin and make up only a small percentage of the drift in the lake basin.

The lake continued to grow in size as the glaciers got smaller. Various lake levels related to glacial retreats and advances and glacial rebound have left a complex series of deposits around the lake margin (Hough, 1958), but only a few of these changes are recorded by sediments in deep water. Sometime

after the Two Rivers glacier had reached its maximum extent, large influxes of reddish brown rock flour began to be deposited in the lake. This clay-size material was deposited in the deeper water of the lake, forming the Sheboygan and South Haven Members of the Lake Michigan Formation. Northernmost samples of the South Haven are varved, but cores from the southern end of the lake show no obvious varving, indicating possible climatic differences affecting sedimentation even at that early stage of deposition and deglaciation. When the glaciers finally melted back beyond the northern peninsula of Michigan, darker colored sediments began to be deposited in Lake Michigan (Winnetka through Waukegan Members). These were derived from material carried in by rivers and from shoreline erosion and therefore are closer in composition to older tills that surround the lake than to the Two Rivers Till. Sediments of the Lake Michigan Formation overlie the Wadsworth, Shorewood, Manitowoc, and Two Rivers Tills with similar thicknesses and with the same stratigraphy south of Frankfort. These similarities lead to the conclusion that the Lake Michigan Formation began to be deposited only after the glacier front had retreated beyond Frankfort.

Our examination shows that at least four tills underlie Lake Michigan. They can be distinguished on geophysical records and have different compositions, as shown by X-ray diffraction studies of the less than 2 micron fraction. They represent progressively weaker glacial episodes at the close of the Wisconsinan glacial stage. A major shift in source of the glaciers occurred between the deposition of the Wadsworth and the Manitowoc Tills, the intervening Shorewood Till being transitional between the two. The presence of these tills permits us to understand better the several stages involved in the formation of modern Lake Michigan and its sediments.

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## APPENDIX

### SECTION 1: Locations of samples collected on 1973 Midwest Friends of the Pleistocene Field Trip

Location numbers of samples collected on the 1973 Midwest Friends of the Pleistocene field trip are preceded by FOP (fig. 4). Page numbers refer to Evenson, Eschman, and Farrand (1973).

FOP-1. Page 39, stop 1, day 1. Pit in Whitehall moraine on west side of Bus. U.S. 31, near Montague, Michigan.

FOP-2. Page 40, stop 2, day 1. Intersection of Stone Road and Scenic Drive near Benona, Michigan.

FOP-3. Page 47, stop 6, day 1. U.S. 10 east of Ludington, Michigan.

FOP-4. Page 51, stop 9, day 1. Cut on east side of road in north wall of Manistee River Valley, near Brethren, Michigan.

FOP-5. Page 50, stop 8, day 1. Bluff of Lake Michigan, Orchard Beach State Park, Michigan.

FOP-6. Page 58, stop 4, day 2. Gravel pit near Wisc. 42, NE $\frac{1}{4}$ NE $\frac{1}{4}$  Sec. 36, T. 20 N., R. 24 E., Two Rivers, Manitowoc County, Wisconsin. Type section of Two Rivers Till Member.

FOP-7. Page 56, stop 2, day 2. Silver Creek Park, Manitowoc, Wisconsin.

FOP-8. Page 55, stop 1, day 2. Point Creek, County Highway, near Cleveland, Wisconsin.

Other sample numbers on figure 4 refer to core descriptions in section 2 of appendix.





## SECTION 2: Core Descriptions

All cores described here are gravity cores, 1 7/8 inches (47 mm) in diameter, from Lake Michigan taken from the R. V. *INLAND SEAS* during October 1972. They are described by stratigraphic unit (fig. 3), and colors given are those of the standard Munsell notation. Locations are shown on figure 4.

### CORE 870

Lat. 43°08.3'N., long. 86°25.2'W.;  
water depth 215 ft (65.5 m).

Pleistocene Series	Depth
Lake Michigan Formation	(cm)
Waukegan Member	
1. Sand, dark gray, clayey; 5 Y 4/1 . . . . .	5.5
2. Silt, dark gray, sandy at top, increasing in clay to base; faint black beds and mottling; 5 Y 4/1 . . . . .	210.0
3. Silt, trace of sand, gray; shells; 5 Y 5/1 . . . . .	218.0

### CORE 871

Lat. 43°08.15'N., long. 86°31.05'W.;  
water depth 340 ft (103.6 m).

Pleistocene Series	Depth
Lake Michigan Formation	(cm)
Waukegan Member	
1. Silt, very sandy at top, brown; shells; 10 YR 4/3 . . . . .	16.1
Lake Forest Member	
2. Clay, sandy, gray; black beds; 10 YR 5/1 . . . . .	59.5
3. Sand, gray, clayey; 10 YR 5/1 . . . . .	64.5

4. Clay, sandy, grayish brown; black mottling; 10 YR 5/2 . . . . .	67.3
5. Sand, clayey, gray; black bed at base; shells; 10 YR 5/1 . . . . .	71.5

### Winnetka Member

6. Clay, brown; some sand; faint black beds; 7.5 YR 5/2 . . . . .	168.0
7. Clay, brown; no visible bedding; 7.5 YR 5/2 . . . . .	194.0

### Sheboygan Member

8. Clay, reddish brown; faint reddish gray beds; 5 YR 5/3 . . . . .	205.0
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### Wilmette Bed

9. Clay, greenish gray; black mottling at top and base; 5 GY 4/1 . . . . .	211.5
10. Clay, alternating beds of reddish gray (5 YR 5/2) and reddish brown (5 YR 5/3) . . . . .	226.0

### South Haven Member

11. Clay, reddish brown; very faint bedding; 5 YR 5/3 . . . . .	270.0
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(continued)

Equality Formation  
Carmi Member

12. Clay, silty and sandy,  
brown; firm; clay pebbles;  
7.5 YR 5/2 . . . . . 296.0

Wedron Formation  
Shorewood Till Member

13. Till?, clay, silty, pinkish  
gray; trace of sand;  
7.5 YR 6/2 . . . . . 302.0

CORE 872

Lat. 43°11.7'N., long. 86°31.0'W.;  
water depth 347 ft (105.8 m).

Pleistocene Series	Depth
Lake Michigan Formation	(cm)
Waukegan Member	

1. Sand, dark yellowish  
brown; some silt;  
10 YR 4/4 . . . . . 11.9

Waukegan Member (?)

2. Silt, sandy, dark gray;  
black mottling; shells;  
5 Y 4/1 . . . . . 33.0

Lake Forest Member

3. Clay, sandy, gray; black  
mottling and beds;  
10 YR 6/1 . . . . . 59.0

Winnetka Member

4. Clay, sandy, grayish brown;  
faint bedding; black beds  
and mottling; 10 YR 5/2 . . 173.0
5. Clay, grayish brown to  
brown; varves (?); some  
beds of coarse silt and  
fine sand; 10 YR 5/2 to  
7.5 YR 5/2 . . . . . 258.5

Equality Formation  
Carmi Member

6. Clay, gray to brown;  
fine sand to coarse silt  
beds; clay pebbles;  
10 YR 5/1; 7.5 YR 5/2;  
5 YR 5/2 . . . . . 288.0

CORE 873

Lat. 43°11.7'N., long. 86°27.4'W.;  
water depth 180 ft (54.9 m).

Pleistocene Series	Depth
Lake Michigan Formation	(cm)
Waukegan Member (?)	

1. Sand, brown; a little  
silt and clay; a few  
shells; 10 YR 5/3 . . . . . 27.0

CORE 875

Lat. 43°05.2'N., long. 86°43.3'W.;  
water depth 350 ft (106.7 m).

Pleistocene Series	Depth
Lake Michigan Formation	(cm)
Waukegan Member	

1. Silt and sand, dark  
gray to brown; hard  
silt beds; 10 YR 3/1  
to 3/3 . . . . . 7.0
2. Silt, black, soft;  
5 Y 2/1 . . . . . 17.0

3. Silt, clayey, dark gray;  
black beds and mottling;  
5 Y 4/1 . . . . . 71.0

Lake Forest Member

4. Clay, gray; black beds  
and mottling; 10 YR 5/1 . . 122.0

Winnetka Member

5. Clay, brown; faint black beds and mottling; a few shells; 7.5 YR 5.2 . . . . 209.0

Sheboygan Member

6. Clay, reddish gray; trace of black mottling; 5 YR 5/2 . . . . . 259.0

Wilmette Bed

7. Clay, dark gray; black mottling; 5 Y 4/1 . . . . . 268.5

8. Clay, reddish gray; trace of black mottling; faint bedding; 5 YR 5/2 . . . . . 282.0

9. Clay, reddish brown; 5 YR 5/3 to 5/4 . . . . . 291.5

South Haven Member

10. Clay, reddish brown; faint bedding; 5 YR 5/3 . . . . . 336.5

CORE 876

Lat. 43°15.5'N., long. 86°56.0'W.;  
water depth 360 ft (109.7 m).

Pleistocene Series	Depth
Lake Michigan Formation	(cm)
Waukegan Member	

1. Clay, silty, brown; thin beds of silt; 10 YR 5/3 . . . . . 13.0

Lake Forest Member

2. Clay, gray; black mottling; a few shells; 10 YR 5/1 . . . 61.5

Winnetka Member

3. Clay, brown; faint black beds; 7.5 YR 5/2 . . . . . 156.0

Sheboygan Member

4. Clay, gray to reddish brown; black mottling; 5 YR 5/1 to 5/2 . . . . . 177.0

Wilmette Bed

5. Clay, dark gray; black mottling; 5 Y 4/1 . . . 187.0

6. Clay, interbedded reddish brown and reddish gray; 5 YR 5/2; 5 YR 5/4 . . . . 208.0

South Haven Member

7. Clay, reddish brown; faint bedding; 5 YR 5/3 . . . . . 251.0

CORE 877

Lat. 43°25.9'N., long. 86°56.0'W.;  
water depth 474 ft (144.5 m).

Pleistocene Series	Depth
Lake Michigan Formation	(cm)
Waukegan to Winnetka Members undivided	

1. Silt, clayey, black; 5 YR 2/1 . . . . . 4.0
2. Silt, clayey, very dark gray; black beds and mottling; base gradational; 5 Y 3/1 . . . . . 67.0
3. Clay, silty, dark gray; black beds and mottling; becomes gradationally more clayey and brownish downward; 5 Y 4/1 to 10 YR 4/1 to 10 YR 5/2 . . . . . 350.0

CORE 878

Lat. 43°36.4'N., long. 86°56.0'W.;  
water depth 320 ft (97.5 m).

Pleistocene Series	Depth
Equality Formation	(cm)
Carmi Member	



1. Sand, coarse; dark yellowish brown; 10 YR 4/4 . . . . . 0.5
2. Clay, reddish brown; sandy and silty; clay pebbles; 5 YR 5/3 . . . . . 16.0
3. Clay, grayish brown; small pebbles; 10 YR 5/2 . . . . . 109.0
4. Clay, gray; faint distorted bedding; 5 YR 5/1 . . . . . 121.0
5. Clay-pebble conglomerate, reddish gray; clay pebbles in a clayey matrix containing some silt and sand; 5 YR 5/2 . . 134.0

CORE 879

Lat. 43° 57.1'N., long. 86° 58.0'W.;  
water depth 535 ft (163.1 m).

Pleistocene Series	Depth
Lake Michigan Formation	(cm)
Waukegan Member	

1. Silt, very dark gray; trace of black mottling; very soft at top; 5 Y 3/1 . . . . . 115.0
2. Clay, silty, very dark gray; closely spaced black beds and black mottling; 5 Y 3/1 . . . . . 180.0

Lake Forest Member

3. Clay, gray; closely spaced faint black beds; 10 YR 5/1 . . . . . 258.5

Winnetka Member

4. Clay, brown; faint black beds; 7.5 YR 5/2 . . . . . 281.0

Sheboygan Member

5. Clay, reddish gray to reddish brown; faint bedding; trace of black mottling; 5 YR 5/2 to 5/3 . . . . . 318.0

CORE 880

Lat. 43° 57.1'N., long. 86° 56.0'W.;  
water depth 474 ft (144.5 m).

Pleistocene Series	Depth
Lake Michigan Formation	(cm)
Waukegan Member	

1. Sand, dark brown; 7.5 YR 4/4 . . . . . 0.1

Sheboygan Member

2. Clay, reddish brown; faint bedding; 5 YR 5/3 to 5/4 . . . . . 34.5

South Haven Member

3. Clay, reddish brown; faint bedding of alternating lighter and darker layers; 5 YR 5/4 . . . . . 140.0

Equality Formation  
Carmi Member

4. Clay, pinkish gray to reddish brown; some silt layers; clay pebbles; 5 YR 6/2 to 5 YR 5/3 . . . 163.5
5. Silt, clayey, pinkish gray; thin beds; 7.5 YR 6/2 . . . . . 169.0
6. Alternating beds 3 to 10 cm thick of clay-pebble conglomerate, reddish brown, and clay, pinkish gray; 5 YR 6/2; 5 YR 5/3 . . . . 342.0

CORE 883

Lat.  $43^{\circ}57.1'N.$ , long.  $86^{\circ}50.9'W.$ ;  
water depth 539 ft (161.2 m).

Pleistocene Series	Depth
Lake Michigan Formation	(cm)
Waukegan Member	
1. Lost . . . . .	10.0
2. Silt, clayey, very dark gray; faint black beds becoming more numerous downward; soft; 5 Y 3/1 . . . . .	151.0
3. Clay, silty, dark gray; black beds and mottling; 5 Y 4/1 . . . . .	297.0

Lake Forest Member

4. Clay, gray; faint black beds and mottling; 5 Y 5/1 . . . . .	364.0
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CORE 884

Lat.  $44^{\circ}06.9'N.$ , long.  $86^{\circ}52.9'W.$ ;  
water depth 512 ft (156.1 m).

Pleistocene Series	Depth
Lake Michigan Formation	(cm)
Waukegan Member	
1. Silt, clayey, dark brown; trace of sand; thin silt layers; 10 YR 4/2 to 4/4 . . . . .	14.5
Lake Forest Member	
2. Clay, gray; black beds and mottling; 10 YR 5/1 . . . . .	163.0
Winnetka Member	
3. Clay, grayish brown; black beds and mottling; a few shells; 10 YR 5/2 . . . . .	272.0

Sheboygan Member

4. Clay, reddish gray; a few irregular beds of reddish brown clay; 5 YR 5/3 to 5/2 . . . . .	316.0
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Wilmette Bed

5. Clay, gray; black mottling in top 3 cm; 10 YR 5/1 . . . . .	324.5
6. Clay, reddish gray to brown; 5 YR 5/2 to 5/4 . . . . .	336.0

CORE 885

Lat.  $44^{\circ}16.56'N.$ , long.  $86^{\circ}46.8'W.$ ;  
water depth 761 ft (232.0 m).

Pleistocene Series	Depth
Lake Michigan Formation	(cm)
Waukegan Member (0 to 90 cm lost. Description from shipboard notes.)	

1. Silt, dark brown; sand . . . . .	10.0
2. Silt, gray; black beds . . . . .	63.0

Lake Forest Member

3. Clay, grayish brown; black beds . . . . .	90.0
4. Clay, gray; shells; prominent black beds and mottling; 10 YR 5/1 . . . . .	150.0

Winnetka Member

5. Clay, brown; black beds and mottling; 7.5 YR 5/2 . . . . .	189.5
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Sheboygan Member

6. Clay, reddish brown; trace of black mottling; 5 YR 5/3 . . . . .	260.0
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(continued)

Wilmette Bed

7. Clay, dark gray; black  
mottling; 5 Y 4/1 . . . 273.0

8. Clay, reddish brown to  
reddish gray in thin beds;  
5 YR 5/2 to 5/4 . . . . . 313.0

South Haven Member

9. Clay, reddish brown;  
5 YR 5/3 to 5/4 . . . . . 422.0

Equality Formation

Carmi Member

10. Clay, brown; clay pebbles;  
trace of silt and sand; firm;  
7.5 YR 5/2 . . . . . 439.5

CORE 886

Lat.  $44^{\circ}25.95'N.$ , long.  $86^{\circ}40.7'W.$ ;  
water depth 780 ft (237.7 m).

Pleistocene Series

Lake Michigan Formation

Waukegan Member

Depth  
(cm)

1. Silt, clayey, dark gray;  
trace of sand; soft and water-  
saturated; black mottling  
and beds in lower part;  
5 Y 4/1 . . . . . 42.0

Lake Forest Member

2. Clay, gray; prominent  
black beds and mottling;  
10 YR 5/1 . . . . . 126.0

Winnetka Member

3. Clay, brown; black beds  
and black mottling; a few  
shells; 7.5 YR 5/2 . . . . 157.0  
4. Clay, reddish gray;  
5 YR 5/2 . . . . . 172.0

Sheboygan Member

5. Clay, reddish brown; black  
mottling; 5 YR 5/3 . . . . 187.5

6. Clay, brown; black mottling;  
7.5 YR 5/2 . . . . . 191.0

7. Clay, reddish gray; black  
mottling; 5 YR 5/2 . . . . 205.0

Wilmette Bed

8. Clay, dark gray; black  
mottling; 5 Y 4/1 . . . 214.0

9. Clay, reddish gray inter-  
bedded with reddish brown;  
5 YR 4/2; 5 YR 5/3 . . . . 244.0

South Haven Member

10. Clay, reddish brown; faint  
bedding; 5 YR 5/3 . . . . 323.0

CORE 887

Lat.  $44^{\circ}37.8'N.$ , long.  $86^{\circ}32.8'W.$ ;  
water depth 800 ft (243.8 m).

Pleistocene Series

Lake Michigan Formation

Waukegan Member

Depth  
(cm)

1. Clay, sandy, light  
brown . . . . . 11.0

2. Clay, silty, yellowish  
brown; trace of sand;  
10 YR 6/4 to 5/4 . . . . 28.0

3. Clay, silty, brown; trace of  
sand; hard silt layers up  
to 3 mm thick; 10 YR 5/3 . 33.0

Lake Forest Member

4. Clay, gray; trace of silt and  
sand; black beds in lower  
part; 10 YR 5/1 . . . . . 59.0

Winnetka Member	15. Till, silty, clayey, sandy, brown; 7.5 YR 5/2 . . . . . 357.0
5. Clay, silty, grayish brown to brown; black beds and mottling; trace of sand; 1 mm sand bed at base; 10 YR 5/2 to 7.5 YR 5/2 . . 109.0	CORE 888  Lat. 44°34.4'N., long. 86°15.9'W.; water depth 244 ft (74.4 m).
Sheboygan Member	Pleistocene Series
6. Clay, reddish brown; trace of black mottling; 5 YR 5/2 . . . . . 171.5	Lake Michigan Formation
	Waukegan Member
Wilmette Bed	1. Sand, gray; alternating thin beds of sand and beds of clayey silty sand 1 cm thick; soft; 10 YR 5/1 . . . . . 69.5
7. Clay, dark gray; black mottling; 5 Y 4/1 . . . 181.5	2. Clay, sandy, gray; thin bedding; very faint black beds; 10 YR 5/1 . . . . . 170.0
8. Clay, reddish gray to reddish brown; 5 YR 5/2 to 5/3 . . . . . 212.0	3. Silt, clayey, gray; trace of sand; a few thin beds of coarse sand; irregular black beds; 5 Y 5/1 . . . . . 288.0
South Haven Member	
9. Clay, reddish brown; faint bedding; 5 YR 5/3 . . 273.0	
Equality Formation	
Carmi Member	CORE 891
10. Clay, silty, sandy, reddish brown; thin beds; clay pebbles; 5 YR 5/3 . . . . . 288.0	Lat. 44°28.25'N., long. 86°27.3'W.; water depth 558 ft (170.1 m).
11. Clay-pebble conglomerate, brown; sandy matrix; a few rock pebbles; 7.5 YR 5/2 . 311.5	Pleistocene Series
12. Sand, medium-grained . . . 313.2	Lake Michigan Formation
	Waukegan Member
Wedron Formation	1. Silt, dark gray; trace of sand; lost . . . . . 45.0
Manitowoc Till Member	2. Silt, dark gray; some clay; trace of sand; faint black beds and mottling; 5 Y 4/1 . . . . . 115.0
13. Till, sandy, silty, clayey, brown; 7.5 YR 5/2 . . . . . 348.0	3. Silt, clayey; dark gray; closely spaced black beds; trace of sand; 5 Y 4/1 . . 230.0 (continued)
14. Gravel, sandy . . . . . 351.0	



Lake Forest Member

4. Clay, silty, gray; trace of sand; a few prominent black beds and many faint ones; black mottling;  
5 YR 5/1 . . . . . 396.0

CORE 892

Lat.  $44^{\circ}28.25'N.$ , long.  $86^{\circ}43.0'W.$ ;  
water depth 894 ft (272.5 m).

Pleistocene Series

Lake Michigan Formation  
Waukegan Member

Depth  
(cm)

1. Silt, very dark gray; very soft; some clay; trace of sand;  
5 Y 3/1 . . . . . 42.0
2. Silt, clayey, dark gray; trace of sand; faint black beds and mottling;  
5 Y 4/1 . . . . . 126.0

Lake Forest Member

3. Clay, gray; trace of silt and sand; black beds and mottling; 10 YR 5/1 . . . . 231.0

Winnetka Member

4. Clay, brown; some black beds and mottling;  
7.5 YR 5/2 . . . . . 281.0

Sheboygan Member

5. Clay, brown to reddish brown; trace of black mottling; 5 YR 5/2 to 5/3 . . . . . 339.0

Wilmette Bed

6. Clay, gray; heavy black mottling; 5 Y 4/1 . . . 351.5

7. Clay, reddish gray interbedded with reddish brown; 5 YR 5/2;  
5 YR 5/3 . . . . . 392.5

CORE 893

Lat.  $44^{\circ}28.25'N.$ , long.  $86^{\circ}48.9'W.$ ;  
water depth 840 ft (256.0 m).

Pleistocene Series

Lake Michigan Formation  
Waukegan Member

Depth  
(cm)

1. Silt, clayey, very dark gray; soft; faint black beds; 5 Y 3/1 . . . . 67.0
2. Silt, clayey, dark gray; prominent black beds; 5 Y 4/1 . . . . . 109.0

Lake Forest Member

3. Clay, a little silt, gray; prominent black beds and mottling;  
10 YR 5/1 . . . . . 213.0

Winnetka Member

4. Clay, grayish brown; heavy black mottling in upper part lessening downward; 10 YR 5/2 . . . . 253.0

Sheboygan Member

5. Clay, reddish brown;  
5 YR 5/3 . . . . . 286.0
6. Clay, reddish gray interbedded with reddish brown and brown;  
5 YR 5/2; 5 YR 5/3;  
7.5 YR 5/2 . . . . . 376.5

CORE 894

Lat.  $44^{\circ}28.25'N.$ , long.  $87^{\circ}08.1'W.$ ;  
water depth 720 ft (291.5 m).

Pleistocene Series	Depth
Lake Michigan Formation	(cm)
Waukegan Member	
1. Silt, clayey, dark gray; trace of sand; prominent black beds; 5 Y 4/1 . . . . .	40.0
Lake Forest Member	
2. Clay, gray; a little silt; black beds and mottling; 10 YR 5/1 . . . . .	96.0
Winnetka Member	
3. Clay, brown; black mottling; 7.5 YR 5/2 . . . . .	126.0
Sheboygan Member	
4. Clay, reddish gray; faint black mottling; 5 YR 5/2 . . . . .	220.5
Wilmette Bed	
5. Clay, dark gray; black mottling; 5 Y 4/1 . . . . .	228.5
6. Clay, reddish brown; color bands; 5 YR 5/2; 5 YR 5/3; 5 YR 4/4; 5 YR 5/4 . . . . .	276.0
South Haven Member	
7. Clay, reddish brown; 5 YR 5/3 . . . . .	293.0

CORE 895

Lat.  $44^{\circ}28.25'N.$ ; long.  $87^{\circ}08.1'W.$ ;  
water depth 666 ft (203.0 m).

Pleistocene Series	Depth
Lake Michigan Formation	(cm)
Waukegan Member	
1. Silt, very dark gray; very soft; some clay; 5 Y 3/1 . . . . .	37.0

2. Silt, clayey, dark gray; faint black beds and mottling; 5 Y 4/1 . . . . . 147.0

Lake Forest Member

3. Clay, gray; a little silt; black beds and mottling; 10 YR 5/1 . . . . . 227.0

Winnetka Member

4. Clay, brown; black beds and mottling; 10 YR 5/2 to 7.5 YR 5/2 . . . . . 306.5

Sheboygan Member

5. Clay, alternating beds of reddish brown and reddish gray; 5 YR 5/3; 5 YR 5/2 . . . . . 461.0

Wilmette Bed

6. Clay, dark gray; some black mottling; 5 G 5/1 . . . . . 476.0
7. Clay, alternating beds of reddish brown and reddish gray; 5 YR 5/2; 5 YR 5/3; 5 YR 4/3; 5 YR 4/4 . . . . . 523.0

South Haven Member

8. Clay, reddish brown; faint bedding; 5 YR 5/3 . . . . . 578.0

CORE 896

Lat.  $44^{\circ}28.25'N.$ , long.  $87^{\circ}17.9'W.$ ;  
water depth 400 ft (121.9 m).

Pleistocene Series	Depth
Lake Michigan Formation	(cm)
Waukegan Member	
1. Silt, hard layer; sandy; dark yellowish brown; 10 YR 5/3 . . . . .	0.5
2. Silt, soft, grayish brown; black beds and mottling at base . . . . .	18.0
(continued)	

Lake Forest Member

3. Clay, silty, gray to grayish brown; black beds and mottling; 10 YR 5/1 to 5/2 . . . . . 69.0

Winnetka Member

4. Clay, brown; some shells; black beds and mottling; 7.5 YR 5/2 . . . . . 99.0
5. Silt, clayey, brown; some fine sand; faint black mottling . . . . . 151.0

Sheboygan Member

6. Clay, reddish brown to reddish gray; faint bedding; 5 YR 5/3 to 5/2 . . . . . 296.0

Wilmette Bed

7. Clay, gray; black mottling; irregular black beds; 5 Y 4/1 . . . . . 320.0

8. Clay, interbedded reddish gray and reddish brown; 5 YR 5/2; 5 YR 5/3 . . . . . 375.0

South Haven Member

9. Clay, reddish brown; faint bedding; 5 YR 5/3 . . . . . 469.5

CORE 899

Lat.  $44^{\circ}26.4'N.$ , long.  $87^{\circ}15.0'W.$ ;  
water depth 520 ft (158.5 m).

Pleistocene Series

Lake Michigan Formation

Waukegan Member

Depth  
(cm)

1. Silt, very dark gray; very soft; some clay; 5 Y 3/1 . . . . . 25.0

2. Silt, clayey, very dark gray; very faint black beds; 5 Y 3/1 . . . . . 45.0

3. Silt, clayey, dark gray; black beds and mottling; 5 Y 4/1 . . . . . 128.0

Lake Forest Member

4. Clay, gray; black beds and mottling; 10 YR 5/1 . . . . . 197.0

Winnetka Member

5. Clay, grayish brown; black beds and mottling; 10 YR 5/2 . . . . . 223.0

6. Clay, dark gray; heavily mottled with black; 10 YR 4/1 . . . . . 264.0

7. Clay, grayish brown to brown; black beds and mottling; 10 YR 5/2 to 7.5 YR 5/2 . . . . . 312.0

Sheboygan Member

8. Clay, reddish brown; faint bedding; 5 YR 5/3 . . . . . 332.0

CORE 900

Lat.  $44^{\circ}26.4'N.$ , long.  $87^{\circ}05.1'W.$ ;  
water depth 780 ft (237.7 m).

Pleistocene Series

Lake Michigan Formation

Waukegan Member

Depth  
(cm)

1. Silt, clayey, very dark gray; soft; more clayey downward; trace of black beds and mottling; 5 Y 3/1 . . . . . 134.0

Lake Forest Member

2. Clay, gray; black beds spaced 0.5 to 1 cm apart; 10 YR 5/1 . . . . . 203.0

CORE 901

Lat.  $44^{\circ}16.9'N.$ , long.  $87^{\circ}11.4'W.$ ;  
water depth 400 ft (121.9 m).

Pleistocene Series	Depth
Wedron Formation	(cm)
Manitowoc Till Member	
1. Till, sandy, silty, clayey, brown; some reddish brown; includes irregular bands of grayish brown till; rock pebbles up to 1 cm; 7.5 YR 5/2; 5 YR 5/3; 10 YR 5/2 . . . . .	153.0

CORE 902

Lat.  $44^{\circ}07.4'N.$ , long.  $87^{\circ}17.6'W.$ ;  
water depth 490 ft (149.4 m).

Pleistocene Series	Depth
Lake Michigan Formation	(cm)
Waukegan Member	
1. Silt, brown, sandy; soft; 10 YR 4/3 to 10 YR 5/3 . . . . .	14.0
2. Silt, hard yellowish brown bed; 10 YR 5/4 . . .	14.3
3. Clay, silty, brown; trace of sand; shells; beds of clayey sand; 7.5 YR 5/2 . .	32.0
Winnetka Member	
4. Clay, silty, brown; shells; black beds and mottling; 7.5 YR 5/2 . . .	92.0
Sheboygan Member	
5. Clay, reddish brown to reddish gray; 5 YR 5/2 to 5/3 . . . . .	245.0

Wilmette Bed

6. Clay, gray; black beds  
and mottling; 5 Y 4/1 . 272.5

7. Clay, alternating color  
bands of reddish gray  
(5 YR 5/2) and reddish  
brown (5 YR 5/3) . . . . . 315.0

South Haven Member

8. Clay, reddish brown; faint  
bedding; 5 YR 5/3 . . . . . 330.0

CORE 903

Lat.  $43^{\circ}57.8'N.$ , long.  $87^{\circ}22.2'W.$ ;  
water depth 325 ft (99.1 m).

Pleistocene Series	Depth
Lake Michigan Formation	(cm)
Waukegan Member	
1. Sand, fine, dark yellowish brown; 10 YR 4/4 . . . . .	1.0
2. Silt, sandy, dark gray; black beds and mottling; 10 YR 4/1 to 4/2 . . . . .	17.0
Lake Forest Member	
3. Clay, gray; black beds and mottling; 10 YR 5/1 . . . . .	59.0
Winnetka Member	
4. Clay, sandy, brown; shells; some black mottling; 7.5 YR 5/2 . . . . .	77.0
5. Sand, coarse, pebbly; shells . . . . .	81.0

(continued)



Unnamed formation  
Two Rivers Till Member

6. Till, clayey; some sand and a few pebbles; reddish brown; 5 YR 5/3 . . 149.0

CORE 904

Lat.  $43^{\circ}45.0'N.$ , long.  $87^{\circ}22.2'W.$ ;  
water depth 313 ft (95.4 m).

Pleistocene Series  
Lake Michigan Formation  
Waukegan Member

1. Silt, clayey; some fine sand; brown; 10 YR 5/3 . . . . . 1.0
2. Clay, silty, brown; some sand; 10 YR 5/3 . . . . . 15.0

Sheboygan Member

3. Clay, alternating beds of reddish brown colors; 5 YR 5/3; 5 YR 5/4 . . . . 52.0

South Haven Member

4. Clay, reddish brown, faint bedding; 5 YR 5/3 . . . . . 148.0

Equality Formation  
Carmi Member

5. Sand, clayey, reddish brown; 5 YR 5/3 . . . . . 150.0
6. Alternating beds of clay, reddish brown, and clay-pebble conglomerate, also reddish brown; 5 YR 5/3 . . 259.0

Wedron Formation  
Manitowoc Till Member

7. Till, clayey, brown; pebbles; 7.5 YR 5/2 . . . . 328.0

CORE 905

Lat.  $43^{\circ}45.0'N.$ , long.  $87^{\circ}30.4'W.$ ;  
water depth 298 ft (90.8 m).

Pleistocene Series  
Lake Michigan Formation  
Waukegan Member

1. Sand, coarse, dark yellowish brown; unconsolidated; 10 YR 4/4 . . . . . 3.0

Sheboygan Member

2. Clay, sandy, reddish brown; very sandy at top; beds of silty sand; 5 YR 5/3 . . . . . 17.0
3. Clay, silty, reddish gray; thin silty sand beds 5 to 6 cm apart; 5 YR 5/2 . . . . . 194.0

Wilmette Bed

4. Clay, dark gray; black mottling; 5 Y 4/1 . . . 210.0

5. Clay, reddish gray to brown; trace of black mottling; 5 YR 5/2 to 5 YR 5/3 to 7.5 YR 4/2 . . 219.0

South Haven Member (?)

6. Clay, brown; no visible bedding; 7.5 YR 5/2 . . . . 233.0
7. Clay, reddish gray; faint bedding; silty beds in lower 15 cm; 5 YR 5/2 . . . 287.0

CORE 909

Lat.  $43^{\circ}34.5'N.$ , long.  $87^{\circ}22.1'W.$ ;  
water depth 451 ft (137.5 m).

Pleistocene Series  
Lake Michigan Formation  
Waukegan Member

Depth  
(cm)

CORE 910

Lat.  $43^{\circ}24.3'N.$ , long.  $87^{\circ}23.3'W.$ ;  
water depth 345 ft (105.2 m).

1. Silt, gray; very soft . . . . . 3.0
2. Silt, clayey, brownish gray; mottled . . . . . 12.0
3. Silt, hard yellow-brown layer . . . . . 13.0
4. Silt, clayey, dark gray; soft; 10 YR 4/1 . . . . . 20.0
5. Clay, silty, dark gray; black beds and mottling; 10 YR 4/1 . . . . . 28.5

Lake Forest Member

6. Clay, gray; silty in upper part; black beds and mottling; 10 YR 5/1 . . . . . 115.0

Winnetka Member

7. Clay, gray, more brownish than 6; faint black beds and mottling; 10 YR 5/1 . . . . 167.0

Sheboygan Member

8. Clay, reddish gray; faint bedding; trace of black mottling; 5 YR 5/2 . . . . 274.0

Wilmette Bed

9. Clay, dark gray; black mottling; 5 Y 4/1 . . . 294.0
10. Clay, interbedded reddish gray (5 YR 5/2) and reddish brown (5 YR 5/3 to 5/4) . . 344.5

South Haven Member

11. Clay, reddish brown; 5 YR 5/3 . . . . . 364.0

Pleistocene Series  
Lake Michigan Formation  
Waukegan Member

Depth  
(cm)

1. Silt, dark brown . . . . . 1.0

Sheboygan Member

2. Clay, reddish brown; color banding; 5 YR 5/4; 5 YR 5/3 . . . . 25.0

South Haven Member

3. Clay, reddish brown; faint bedding; 5 YR 5/3 . . . . . 252.0

Equality Formation  
Carmi Member

4. Clay-pebble conglomerate, reddish brown; 5 YR 5/3 . . . . . 265.0
5. Clay, a few clay pebbles; reddish brown; 5 YR 5/3 to 5/4 . . 322.0
6. Clay, sandy, brown; 7.5 YR 5/2 . . . . . 328.0
7. Clay, reddish brown and brown beds alternating; 5 YR 5/2; 7.5 YR 5/2 . . . 347.0
8. Clay, sandy, grayish brown; a few rock pebbles; clay pebbles; 10 YR 5/2 . . . . 357.0

CORE 911

Lat.  $43^{\circ}13.9'N.$ , long.  $87^{\circ}22.1'W.$ ;  
water depth 295 ft (89.9 m).

Pleistocene Series		Depth	5. Sand, clayey, brown;	
Lake Michigan Formation		(cm)	shells; 7.5 YR 5/2 . . . .	25.0
Waukegan Member				
1. Sand, dark brown;			Sheboygan Member	
silt and clay;			6. Clay, color banding,	
10 YR 4/3 . . . . .	0.5		reddish brown; 5 YR 5/3;	
			5 YR 5/4 . . . . .	64.0
2. Clay, silty, grayish			South Haven Member	
brown; faint mottling;			7. Clay, reddish brown;	
snail shells; sharp			faint bedding;	
lower contact; sandy at			5 YR 5/3 . . . . .	273.0
base; 10 YR 5/2 . . . . .	15.0			
South Haven Member			Equality Formation	
3. Clay, reddish brown;			Carmi Member	
faint bedding; sharp			8. Clay, silty, reddish	
contacts; 5 YR 5/3 . . . .	82.0		brown; faint beds;	
Wedron Formation			small clay pebbles;	
Shorewood Till Member			5 YR 5/2 to 5/3 . . . . .	291.0
4. Till, clay, silt, a				
little sand; rock			CORE 918	
pebbles, clay pebbles;			Lat. 42°43.2'N., long. 87°22.10'W.;	
brown; 7.5 YR 5/2 . . . .	221.0		water depth not recorded.	
CORE 912			Pleistocene Series	Depth
Lat. 43°03.35'N., long. 87°36.3'W.;			Lake Michigan Formation	(cm)
water depth 266 ft (81.1 m).			Waukegan Member	
Pleistocene Series	Depth		1. Silt, dark brown; fine	
Lake Michigan Formation	(cm)		sand and some clay;	
Waukegan Member			hard silt layers;	
1. Sand, dark brown,			10 YR 3/3 to 5/3 . . . . .	9.0
silty; soft;				
7.5 YR 4/4 . . . . .	0.5		2. Clay, silty, brown;	
			trace of sand; sharp	
2. Silt, sandy, brown;			base; 10 YR 5/3 . . . . .	15.0
shells; 7.5 YR 5/4 . . . .	4.0		Lake Forest Member	
3. Sand, brown; silt and			3. Clay, silty, gray;	
clay; 7.5 YR 5/4 . . . . .	7.0		shells; faint black	
			beds; 10 YR 5/1 . . . . .	50.0
4. Clay, silty, brown;			Sheboygan Member	
shells; trace of sand;			4. Clay, sandy, reddish	
faint bedding;			gray; shells; sand lens	
7.5 YR 5/4 . . . . .	20.0		at base; 5 YR 5/2 . . . . .	55.0

Wilmette Bed

5. Clay, gray;  
10 YR 5/1 . . . . . 59.0

6. Clay, interbedded  
reddish gray (5 YR 5/2)  
and reddish brown  
(5 YR 5/3 to 5/4) . . . . . 110.0

South Haven Member

7. Clay, reddish brown;  
faint bedding; trace  
of sand; 5 YR 5/3 . . . . . 285.0

Equality Formation

Carmi Member

8. Clay, silty, faint  
bedding; clay  
pebbles; reddish  
brown (5 YR 4/4) to  
brown (7.5 YR 5/2) to  
grayish brown  
(10 YR 5/2) . . . . . 324.0

9. Clay-pebble conglomerate;  
clay pebbles up to 1 cm  
and rock pebbles up to  
2 cm; sandy clay matrix . . 334.5

CORE 919

Lat. 43° 32.9'N., long. 87° 22.1'W.;  
water depth 394 ft (120.1 m).

Pleistocene Series

Lake Michigan Formation

Waukegan Member

Depth

(cm)

1. Silt, very dark gray; a  
gradual increase downward  
in number of black beds;  
5 Y 3/1 . . . . . 136.5

Lake Forest Member

2. Clay, gray; a little silt;  
black beds and mottling;  
10 YR 5/1 . . . . . 209.5

Winnetka Member

3. Clay, grayish brown;  
shells; trace of sand;  
black beds and mottling;  
10 YR 5/2 . . . . . 306.0

4. Clay, brown; faint black  
mottling; 7.5 YR 5/2 . . . 333.0

5. Clay, reddish gray; faint  
black mottling; 5 YR 5/2 . 349.5

Sheboygan Member

6. Clay, gray to reddish  
gray; 5 YR 5/1 to 5/2 . . . 379.0

Wilmette Bed

7. Clay, dark gray; black  
mottling in upper part;  
5 Y 4/1 . . . . . 394.0

CORE 920

Lat. 42° 26.8'N., long. 87° 36.2'W.;  
water depth 222 ft (67.7 m).

Pleistocene Series

Lake Michigan Formation

Waukegan Member

Depth

(cm)

1. Sand, clayey, dark  
brown; 10 YR 4/3 . . . . . 3.0

2. Clay, sandy, dark  
grayish brown;  
10 YR 4/2 . . . . . 5.5

Lake Forest Member

3. Silt, clayey, dark  
gray; faint black beds  
and mottling; 10 YR 4/1 . . 38.0

Winnetka Member (?)

4. Clay, silty, grayish  
brown; faint black beds  
and mottling; 10 YR 5/2 . . 171.0  
(continued)



Winnetka Member

5. Clay, brown; some sand and silt; faint bedding; gray silt beds; 7.5 YR 5/2 . . . . . 250.0

CORE 922

Lat. 42°26.8'N., long. 87°27.9'W.;  
water depth 312 ft (95.1 m).

Pleistocene Series  
Lake Michigan Formation  
Waukegan Member

- |  | Depth<br>(cm) |
|--|---------------|
| 1. Sand, clayey, dark grayish brown; 10 YR 4/2 . . . . .   | 2.0           |
| 2. Clay, dark gray; hard silt layers; black beds and mottling in lower part; 10 YR 4/1 . . . . . | 22.5          |

Lake Forest Member

3. Clay, gray; a little sand; shells; black beds and mottling; 10 YR 5/1 . . . . . 96.0

Winnetka Member

4. Clay, brown; shells; black beds and mottling; 7.5 YR 5/2 . . . . . 142.0

Sheboygan Member

5. Clay, silty, brown; closely spaced beds of light and dark clay (varves?); beds of silt; 7.5 YR 5/2 . . . . . 206.0
6. Clay, reddish brown to reddish gray; 5 YR 5/3 to 5/2 . . . . . 231.0

Wilmette Bed

7. Clay, dark gray; black mottling in top 5 cm; 5 Y 4/1 . . . . . 247.0

8. Clay, interbedded reddish brown and reddish gray; 5 YR 5/2; 5 YR 4/4 . . . . . 289.0

South Haven Member

9. Clay, reddish brown; faint bedding; 5 YR 5/3 . . . . . 323.0

CORE 923

Lat. 42°25.9'N., long. 87°22.1'W.;  
water depth 366 ft (111.6 m).

Pleistocene Series  
Lake Michigan Formation  
Waukegan Member

- |  | Depth<br>(cm) |
|--|---------------|
| 1. Silt, very dark gray; very soft; trace of black mottling; 5 Y 3/1 . . . . . | 70.0          |

Lake Forest Member

2. Clay, gray; black beds and mottling; 10 YR 5/1 . . . . . 104.0

Winnetka Member

3. Clay, brown; black mottling; 7.5 YR 5/2 . . . . . 144.0

Sheboygan Member

4. Clay, reddish brown to reddish gray; some black beds and mottling; 5 YR 5/2 to 5/3 . . . . . 180.0

Wilmette Bed

5. Clay, dark gray; trace of black mottling at top; 5 Y 4/1 . . . . . 192.0
6. Clay, interbedded gray and reddish brown; 5 YR 5/1; 5 YR 5/3; 5 YR 5/4 . . . . . 222.0

South Haven Member

7. Clay, reddish gray;  
5 YR 5/2 . . . . . 380.0

CORE 928

Lat.  $41^{\circ}52.7'N.$ , long.  $87^{\circ}22.1'W.$ ;  
water depth 82 ft (25.0 m).

Pleistocene Series  
Equality Formation  
Carmi Member

1. Clay, gray; stiff,  
sticky; faint bedding;  
silt beds; 10 YR 5/1 . . . 99.0

CORE 933

Lat.  $42^{\circ}14.95'N.$ , long.  $87^{\circ}25.95'W.$ ;  
water depth 260 ft (79.2 m).

Pleistocene Series  
Lake Michigan Formation  
Waukegan Member

1. Silt, clayey, brown;  
some sand; hard silt  
layers; 7.5 YR 5/2 . . . . 19.0

Lake Forest Member

2. Clay, grayish brown; black  
beds and mottling; trace  
of sand; 10 YR 5/2 . . . . 75.0

Winnetka Member

3. Clay, brown; some silt  
and sand; 7.5 YR 5/2 . . . 112.0

South Haven Member

4. Clay, reddish brown;  
beds of silt;  
5 YR 5/3 to 5/4 . . . . . 318.0

CORE 934

Lat.  $42^{\circ}14.95'N.$ , long.  $87^{\circ}29.8'W.$ ;  
water depth 213 ft (64.9 m).

Pleistocene Series  
Lake Michigan Formation  
Lake Forest Member

Depth  
(cm)

1. Clay, brown; soft; silty  
and sandy; 7.5 YR 5/4 . . . 13.0

CORE 937

Lat.  $42^{\circ}23.3'N.$ , long.  $87^{\circ}22.2'W.$ ;  
water depth 342 ft (104.2 m).

Pleistocene Series  
Lake Michigan Formation  
Waukegan Member

Depth  
(cm)

1. Silt, very dark grayish  
brown; soft; faint  
bedding; 10 YR 3/2 . . . . 5.0

2. Silt, clayey, very  
dark gray; 5 Y 3/1 . . . . 24.0

3. Silt, clayey, very  
dark gray; black beds  
and mottling . . . . . 45.0

Lake Forest Member

4. Clay, silty, gray;  
black beds and  
mottling; 10 YR 5/1 . . . . 102.5

Winnetka Member

5. Clay, brown; a few  
shells; black beds and  
mottling; 7.5 YR 5/2 . . . 140.0

Sheboygan Member

6. Clay, reddish gray; black  
mottling; 5 YR 5/2 . . . . 191.0

Wilmette Bed

7. Clay, dark gray; black  
mottling; 5 Y 4/1 . . . 205.0

8. Clay, interbedded  
reddish brown and  
reddish gray;  
5 YR 5/2; 5 YR 5/3;  
5 YR 5/4 . . . . . 262.0  
(continued)

South Haven Member

9. Clay, 1 cm bands,  
alternately light and  
dark reddish brown;  
some silt beds;  
5 YR 5/3; 5 YR 4/4 . . . . 471.0

Equality Formation

Carmi Member

10. Clay-pebble conglomerate,  
reddish brown; clay pebbles  
1 cm in diameter in silty  
clay matrix; trace of sand  
and a few rocks . . . . . 499.0

CORE 938

Lat. 42°23.3'N., long. 87°28.6'W.;  
water depth 287 ft (87.5 m).

Pleistocene Series

Lake Michigan Formation

Waukegan Member

1. Silt, dark grayish  
brown; some sand and  
clay; hard silt beds;  
10 YR 4/2 . . . . . 14.0

Lake Forest Member

2. Clay, silty, gray; black  
beds and mottling;  
10 YR 5/1 . . . . . 57.0

Winnetka Member

3. Clay, grayish brown to  
brown; a few shells;  
7.5 YR 5/2 to 10 YR 5/2 . . 82.0

Sheboygan Member

4. Clay, reddish gray;  
varved?; faint black  
mottling; 5 YR 5/2 to  
5/3 . . . . . 148.5

Wilmette Bed

5. Clay, dark gray; black  
mottling; 5 Y 4/1 . . . 165.0

6. Clay, interbedded reddish  
gray and reddish brown;  
5 YR 5/2; 5 YR 5/3 . . . . 225.0

South Haven Member

7. Clay, reddish brown;  
5 YR 5/3 . . . . . 313.0

CORE 939

Lat. 42°23.3'N.; long. 87°32.4'W.;  
water depth 252 ft (76.8 m).

Pleistocene Series

Lake Michigan Formation

Waukegan Member

Depth

(cm)

1. Silt, dark gray; soft;  
trace of sand; trace of  
faint black mottling;  
a few faint black beds;  
5 Y 4/1 . . . . . 38.0

Lake Forest Member

2. Clay, dark gray; a little  
sand; black beds;  
10 YR 4/1 . . . . . 70.0

3. Clay, grayish brown; faint  
black beds; shells;  
10 YR 5/2 . . . . . 185.0

Winnetka Member

4. Clay, brown; trace of sand;  
a few shells; 7.5 YR 5/2 . . 247.0

Equality Formation

Carmi Member

5. Clay, grayish brown; a few  
clay pebbles; 10 YR 5/2 . . 266.0

6. Clay-pebble conglomerate,  
brown; sandy clay matrix;  
a few rock pebbles;  
7.5 YR 5/2 . . . . . 289.0

7. Thin beds of clay-pebble  
conglomerate interbedded  
with clay; grayish brown;  
10 YR 5/2 . . . . . 328.0

3. Silt, clayey, dark gray;  
faint black beds; shells;  
5 Y 4/1 . . . . . 310.0

Lake Forest or Waukegan Member

4. Clay, silty, gray; trace  
of sand; faint black beds;  
10 YR 5/1 . . . . . 352.0

CORE 963

Lat.  $42^{\circ}00.7'N.$ , long.  $86^{\circ}52.1'W.$ ;  
water depth 215 ft (65.5 m).

Pleistocene Series	Depth
Lake Michigan Formation	(cm)
Waukegan Member	

1. Silt, dark gray; a little  
sand; soft; faint black  
beds; 10 YR 4/1 . . . . . 106.0

2. Clay, silty, dark gray;  
faint black beds;  
shells; 5 Y 4/1 . . . . . 250.0

Lake Forest Member

3. Clay, gray; a little silt;  
closely spaced black  
beds; 10 YR 5/1 . . . . . 332.0

CORE 965

Lat.  $42^{\circ}07.05'N.$ , long.  $86^{\circ}45.2'W.$ ;  
water depth 242 ft (73.8 m).

Pleistocene Series	Depth
Lake Michigan Formation	(cm)
Waukegan Member	

1. Silt, very dark gray;  
trace of sand; faint  
bedding; soft at top;  
5 Y 3/1 . . . . . 94.0

2. Silt, clayey, very dark  
gray; faint black beds and  
mottling; 5 Y 3/1 . . . . . 140.0

CORE 966

Lat.  $42^{\circ}05.30'N.$ , long.  $86^{\circ}41.3'W.$ ;  
water depth 178 ft (54.3 m).

Pleistocene Series	Depth
Lake Michigan Formation	(cm)
Waukegan Member	

1. Silt, black, trace of  
sand; soft; 5 Y 2/1 . . . . . 7.0

2. Silt, clayey, dark gray;  
more clayey downward;  
trace of sand; 5 Y 4/1 . . . 183.0

3. Silt, clayey, dark gray;  
faint black beds and  
mottling; 5 Y 4/1 . . . . . 285.0

CORE 969

Lat.  $42^{\circ}14.05'N.$ ; long.  $86^{\circ}39.2'W.$ ;  
water depth 162 ft (49.4 m).

Pleistocene Series	Depth
Lake Michigan Formation	(cm)
Waukegan Member	

1. Silt, dark gray; soft;  
5 Y 3/1 to 4/1 . . . . . 140.0

2. Silt, clayey; trace of  
black mottling; faint  
bedding; 5 Y 4/1 . . . . . 323.0



CORE 970

Lat.  $42^{\circ}29.4'N.$ , long.  $86^{\circ}39.3'W.$ ;  
water depth 260 ft (79.2 m).

Pleistocene Series	Depth
Lake Michigan Formation	(cm)
Waukegan Member	
1. Silt, very dark gray; soft; 5 Y 3/1 . . . . .	47.0
2. Silt, clayey, dark gray; faint black beds and mottling; 5 Y 4/1 . . . . .	109.0
3. Clay, silty, dark gray; black beds and mottling; 10 YR 4/1 . . . . .	143.0
Lake Forest Member	
4. Clay, gray; faint black beds and mottling; shells; 10 YR 5/1 . . . . .	233.0

CORE 971

Lat.  $42^{\circ}50.4'N.$ , long.  $86^{\circ}39.3'W.$ ;  
water depth 290 ft (88.4 m).

Pleistocene Series	Depth
Lake Michigan Formation	(cm)
Waukegan Member	
1. Silt, clayey, very dark gray; sand and hard silt layers near top; black mottling and beds; 5 Y 3/1 . . . . .	41.0
Lake Forest Member	
2. Clay, gray; shells and sand; black beds; 10 YR 5/1 . . . . .	113.0
Winnetka Member	
3. Clay, sandy, grayish brown; black beds and mottling; 10 YR 5/2 . . . . .	143.0
Equality Formation	
Carmi Member	
4. Clay, sandy, reddish gray; very sandy at base; 5 YR 5/2 . . . . .	150.0

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